The Chinese University of Hong Kong

Airborne Suspended Particulate Pollution in Hong Kong

A Thesis Submitted to Fulfil the

Partial Requirement for the Degree of

Master of Philosophy

Division of Geography

Graduate School

by

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June 1983

Acknowledgements

I wish to express my sincere gratitude to my supervisor, Dr. Sheng-I Hsu, for his participation in the design of the sampler, his constructive criticisms, suggestions and thought-provoking discussion. Thanks are also given to Dr. Kin-che Lam, the Co-supervisor, and Dr. Yee Leung for contributing helpful comments and statistical techniques.

I also wish to acknowledge the Institute of Social Studies at The Chinese University of Hong Kong, and the Environmental Protection Advisory Committee of Hong Kong Government for providing research grants. The assistance of the Royal Observatory in providing meteorological data is also appreciated.

Many thanks are also directed to the assistance of my classmates and colleaque. Among these I would especially mention Mr. Lee, Kwong-chi for conducting laboratory measurements, Mr. Philip Yeung for drawing diagrams and maps, and Mrs. Jane Wan for typing the final report.

Finally, special thanks must be given to my sister, Catherine, for spending many hours in typing and my friend, Li-hua Chu for her many encouraging words and unfailing help.

Abstract

The samples of airborne suspended particulates were collected at ground-level and the roof-level ambient air at 5 different sites in Hong Kong by using Hi-Vol air samplers and analyzing some heavy metal pollutants with an atomic absorption spectrophotometer. The implications of the meteorological parameters in the particulate pollution level were evaluated.

The concentrations of total suspended particulates (TSP) and airborne heavy metal pollutants vary with site and time. It was found that at the urban and industrial sites, the mass concentration of TSP exceeded the U.S. primary standards in some of the sampling days. Among the analyzed airborne elements, high lead concentraton is typical as it is in other metropolitan areas in the world. It is above the national ambient air quality standards of many countries. The elements, such as Zn, Pb and Cu, are highly enriched in the suspended particulates relative to crusted soil due to numerous anthropogenic activities.

Vertical variation of the particulate pollution does exist, and it depends on vertical land-use patterns and the ventilation conditions.

Only the weak or insignificant correlations between the concentration and the meteorological parameters, such as wind speed, mixing depth and precipitation, could be found due to the complicit urban physical structure and lack of micro-scale circulation instrumentations.

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CHAPTER I

INTRODUCTION

1.1 The problems

The rapid industrial development during the recent two centuries has resulted in an enormous consumption of natural resources, including various forms of energy. As a consequence, many substances are often concentrated far above the natural cleansing capacity of the environment. When the concentration of these emitted matters attains a certain level, human life and the ecological environment may be seriously affected. Hence an atmospheric pollution problem has developed.

Hong Kong, due to its rapid growth of industrialization and urbanization in the past three decades, is now facing various atmospheric environmental problems. For instance, some great pollution sources, such as electric power plants and incinerators, are sited nearby or inside the populated urban areas; many industrial areas are developed against the residential areas without enough open space or green belts as barriers between each other; during the day time, many roads are congested with motor vehicles, which polluted the atmosphere. Moreover, the existing highly mixed landuse pattern in the residential areas in Hong Kong may lead to a higher degree of air pollution than in other cities and the pollutants emitted by commercial and industrial activities may directly affect the health of the nearby dwellers. As a result, the atmospheric environment of Hong Kong has been deteriorating and hence has aroused much public concern.

However, the atmospheric environment has not yet been effectively managed and controlled in Hong Kong. The Clean Air Ordinance, basically an emission control bill enacted two decades before, only bill to control smoke emission. This means that the ambient air quality, including gases and particulates have not yet been regulated. Since the 1970s, as both the government and the public have expressed much concern about environmental problems, a number of studies dealing with atmospheric pollution in Hong Kong have been undertaken; however, the majority of them are mainly directed to sulfur dioxide. The studies about the present status of the other gaseous pollutants and the airborne suspended particulates in Hong Kong are still insufficient.

Because the present Clean Air Ordinance cannot completely solve air pollution problems nor can it effectively manage the ambient air quality, the Hong Kong government is drafting a comprehensive air quality control bill, under which the colony would be divided into several zones, and the ambient air quality standard for each zone will be declared.

For the establishment of appropriate divisional ambient air quality standard, a comprehensive understanding of the present status of the air quality in Hong Kong is essential. However, the relevant research is insufficient.

1.2 The scope of the study

Major pollutants in the atmosphere comprise gases, particulates, and their combined forms, e.g. smoke. In this study, focus is placed on the airborne suspended particulates.

The mass concentration and the chemical composition of the total suspended particulates (TSP), which reflect the effects of the nearby pollution sources, the nature of the land surface, and the physical and chemical reactions in the atmosphere, are the most important indicators in the study of particulate pollution. It is hoped that by means of studying the mass concentration and the chemical composition of the suspended particulates, a more complete picture of the status of atmospheric pollution in Hong Kong can be offered.

1.3 The Hypothesis

In a metropolitan region, because the land use pattern is quite diversified; the concentrations and qualities of pollutants naturally vary. Moreover, the various densities of population and buildings may contribute to the spatial differences in air pollution.

High and bulky buildings are commonly built in either the commercial or residential areas, Of these buildings the ventilation condition of lower floors is greatly different from that of upper floors; and if the vertical land use patterns are complex, the emission of pollutants from each floor may be of greatly different amounts, therefore, a great variety of air pollution in the vertical dimension may occur.

Moreover, since the suspended particulates stay in the air, its quality, distribution and transportation is more or less affected by various atmospheric elements. Conversely, because of its existance, the nature and process of various atmospheric elements are affected. In a metropolitan region, because of the congested high buildings and various man-made constructions, micrometeorological conditions are varied, and their correlation with the suspended particulate pollution is still full of intricacies. Very often, the appearance, reinforcement or reduction of some climatic elements may greatly affect the degree of air pollution.

For an accurate understanding of the status of air pollution, two tentative hypothesis are suggested and needed evaluation in this study. They are as follows:

(a) The spatial and vertical variation in suspended particulate pollution exists in Hong Kong.

(b) The variability of the meteorological parameters affects the suspended particulate pollution level.

1.4 The limitation of the study

Particulate concentration in the ambient air can be expressed in terms of 24-hour, 8-hour and 1-hour time intervals. However, because of the limitation of available resources and labours, all samples are monitored in 24-hour intervals.

In the analysis of chemical compositions, many toxic elements ought to be considered. However, because of the same reason stated above, only a few heavy metals have been analyzed in this study.

In the study of the enrichment of the elements in the suspended particulates relative to the crustal soil, many elements which is non-volatile and broadly distribute in the crustal soil, such as the Si, Ti, Na, K, Al and Fe, can be taken as the reference elements for calculating the enrichment factor of each airborne element. However, due to the limitation imposed by laboratory facilities, only Fe can be employed in this study. The use of iron as a reference element is not very ideal because iron itself is also one of the pollutants emitted from various industrial activities in Hong Kong. Furthermore, the monitoring site of the campus of C.U.H.K., is also near to the now disused Ma On Shan iron mine.

In the study of the correlation between the meteorological parameters and the particulate pollution level, local meteorological records at the monitoring station should be used. However, in this study, only the records from Royal Observatory are used for most monitoring sites since there are no other effective local weather stations.

1.5 The significance of the study

It is hoped that this study of suspended particulates can provide more valuable information with which the existing gap of knowledge about the atmospheric pollution in Hong Kong can be filled. Moreover, the results of this study may serve as reference for the control and management of the ambient air quality in Hong Kong for both the departments of Hong Kong Government or private agencies concerned.

CHAPTER II

LITERATURE REVIEW

2.1 The definitions of air pollution

Rossano (1969) distinguished three major categories of the air pollution as follows:

(a) Personal - This comprises all gases from cigarette, cigar, and pipe smoking, and the use of household sprays.

(b) Occupational - This category comprises all exposure of persons to pollution at their working place.

(c) Community - Ambient or outdoor air pollution is usually considered as community air pollution.

However, when people think of pollution, they usually have in mind the ambient air pollution, which everybody cannot escape from and can be striken by in the form of short-term disasters, or by long-term influences changing the climate of the planet. Therefore, in this study, only the ambient air pollution will be discussed.

According to the State of Arizona air pollution control regulations (7-1-1.2;3), the definition of air pollution is as follows: "air pollution means the presence in the outdoor atmosphere of one or more air contaminants or combination therefore in such quantities and of such duration as are or may tend to be injurious to human, plant, or animal life, or property". Air contaminants include smoke, vapors, charred paper, dust, soot, grime, carbon fumes, gases, mist, odors, particulate matter, radioactive materials, or noxious chemicals, or any other material in the outdoor atmosphere.

The American Public Health Association presented some definitions of the pollutants. Particulate means "existing in the form of minute separate particles, either solid or liquid". Thus, the airborne suspended particulate can be defined as "A dispersion of solid or liquid particles of microscopic size in the atmosphere" (APHA, 1969).

2.2 The ambient air quality standards for particulate matter

According to the U.S. National Clean Air Act (EPA, 1971), the "ambient air" means that portion of the atmosphere, external to buildings, to which the general public has access.

However, Newill (1976) gave the ambient air quality standards a definition: "Air quality standards are legal limits placed on levels of air pollutants in the ambient (outdoor) air during a given period of time. As such, they characterize the allowable level of a pollutant or a class of pollutants in the atmosphere and thus define the amount of exposure permitted to the population and/or to ecological system". Newill also indicated that air quality standards have evolved differently in different countries, according to exposure conditions, the socio-economic situation, and the importance of other health-related problems.

At present, ambient air quality standards and regulations for particulate matters do not exist in many countries. Occupational health and safety standards exist in most countries and usually represent a higher priority concern than that of ambient standards. Some countries indirectly control particulates through regulation of total particulate emissions.

In the United States, the national air quality standards for six common classes of pollutants were announced in 1971 under The Clean Air Act. Under the law, EPA set up two types of air quality standards. Primary standards provide protection for public health and allow an adequate margin of safety. Secondary standards were set up to protect against effects on soil, water, vegetation, materials, animals, weather, visibility, and personal comfort and well-being. States were required to plan to meet the standards by 1975. These standards for particulate matters are listed in Table 2.1.

In addition to the United States, the national ambient air quality standards ($\mu g/m^3$) for suspended particulates for selected countries for various average time were illustrated by Newill (1976) (see Table 2.2). The data showed that although the data bases (the period of time) for each of these standards are the same, the actual concentration chosen for a standard is very different. This again demonstrates that standards are political rather than scientific decisions.

2.3 The background level of suspended particulates

Reither et al. (1976) attempted to establish the global representation of aerosol components. To decrease the influence

Table 2.1 U.S. ambient air quality standard for particulates

National Primary Ambient Air Quality Standard	
Annual geometric mean	75 $\mu g\ m^{-3}$
Maximum 24-hour concentration*	260 $\mu g\ m^{-3}$
National Secondary Ambient Air Quality Standard	
Annual geometric mean	60 $\mu g\ m^{-3}$
Maximum 24-hour concentration*	150 $\mu g\ m^{-3}$
Level of significant harm	1000 $\mu g\ m^{-3}$

* not to be exceeded more than once per year.

Table 2.2 National ambient air quality standards for suspended particulates

Country	Long-term standard		Short-term standard		Notes
	$\mu g/m^3$	Averaging time (hours)	$\mu g/m^3$	Averaging time (minutes)	
Argentina	100	30 days			
Bulgaria, Czechoslovakia, E. Germany, Finland, Romania, U.S.S.R.	150	24	500	30	
Canada- Acceptable level Acceptable level	70 120	1 year 24			a b
Canada- Desirable level	60	1 year			c
Colombia	100	24			
Hungary Hungary, Turkey	200 100	24 24			d, e
Israel Israel	200 75	24 1 year			
Italy	300	24	750	120	f
Japan	100	24	200	60	g
Poland	200 75 130	24 24 1 year	600 200	20 20	h, i
Spain	200 300	30 days 24	 600	 30	j j
British	40 120	1 year 24			k

(to be continued)

Table 2.2 (cont'd)

NOTE:

a. National Air Quality Objectives in Canada

b. Maximum acceptable level in Canada

c. Desirable level in Canada

d. Recommended standard in Turkey

e. Residential areas in Turkey

f. Once is 8 hours in Italy

g. Average of hourly means for 24 hour value in Japan

h. Specially potected areas in Poland

i. Particle size 20 μm.

j. Proposed standard in Spain

k. 98% of observations below this value, the permissible 2% of observations over this limits may not fall on consecutive days

Source: Newill (1976)

of meteorological parameters and local sources, the observatory selected was located about 1000 m above the valley floor of Garmisch-Partenkirchen on the rather rounded top of an almost isolated mountain. Its peak is completely grass-covered. They presented an interim statistical analysis to study aerosol concentration and the matrix of chemical aerosol composition in pure-air conditions. The method will permit systematic analysis of the functional relationship between aerosol components, on one hand, and the controlling meteorological conditions, on the other. The results showed that the aerosol chemical matrix is a function of the controlling atmospheric parameters and of the type of air mass involved. The chemical compositions of those substances are so small that they have to be expressed in ng units.

Adams F., et al. (1980) gave an investigation of background aerosol compositions on a remote mountain station sited at 5220 m above sea level near the La Paz, Bolivia. It is clearly an excellent location for aerosol analysis under pure-air conditions. Concentrations are comparable to previously reported continental nonurban levels. The results showed that the elemental composition is similar to those measured at other remote locations in the Northern Hemisphere and Antaractica.

2.4 The recent studies in urban areas

Many studies concerning particulate pollution in metropolitan areas and relatively unpolluted suburban areas have been done in many developed countries; for instances, Hidy et al. (1975) in

California, Leaderer et al. (1978) in New York, Demuynck et al. (1975) in Belgium and King et al. (1976) in Cleveland. Their results showed that in most metropolitan areas, the ambient air qualities are far above any declared air quality standards. However, in upwind nonurban areas, the ambient air quality may be much better. With regard to chemical compositions, they found that the values of the enrichment factors of many airborne elements are high, which indicates that many particulates are derived from anthropogenic sources. Among them, the absolute concentrations and enrichment factors of lead and cadium are extremely high compared with the background level of these airborne elements. It is believed that the great number of motor vehicles may be the main source of these elements.

In addition, Wong et al. (1981) collected airborne particulates at five different land use sites in the Beijing area by using Hi-Vol air samplers. Variability was found in the particulate pollution level among five sites. It was also found that S, Zn, Pb, and Cu had high values of enrichment factors, but, in comparison with other metropolitan areas in developed countries, the concentration and enrichment factors of Pb were relatively lower.

Pariga et al. (1976) determined the concentration of 25 elements instrumentally by neutron and photon activation analysis in aerosol samples collected at urban and industrial sites in Toronto. Many elements associated with larger aerosols (Al, Ca, Fe, La, Mg, Sm, Sc, Na and Ti) appeared to be mainly soil derived, whereas some elements associated with the smaller size fractions

(Sb, As, Br, Cl, Pb, V and Zn) were abnormally enriched in the atmosphere and appeared to have significant anthropogenic sources.

2.5 The implications of meteorological parameters

The effects of various meteorological parameters on particulates pollution have long been subject to theoretical or experimental research. However, in this study, only precipitation, mixing depth, and wind speed will be discussed.

Precipitation can remove the particulates from the atmosphere through "washout" and "rainout" effects. The "washout" is the removal by precipitation of particles which collect dry particulates (e.g. below cloud base) by inertial collection or, in the case of smaller aerosol particles, diffusion, and also by "phoretic" forces. The latter is the removal as precipitation of particles which have uncleated water condensation which turns into cloud drops which in turn become precipitation particles (Twonmey, 1977). Thus, precipitation is a major factor in cleansing the atmosphere.

Davenport (1978) evaluated the effects of rain on changes in the atmospheric particulate concentration. Measurements were compared with theoretical calculations of particle washout coefficients. The experimental washout coefficients were between $2 \times 10^{-5} S^{-1}$ and $1 \times 10^{-4} S^{-1}$, depending on the raindrop size, distributions and precipitation intensity. These values were one to two orders of magnitude greater than theoretical estimates.

Cade and Junge (1971) and Smith (1971) indicated that most of the aerosols can act upon as condensation nuclei or ice nuclei in the atmosphere. This process may increase the chance of precipitation and cloud volume. Water-soluble, hydroscopic particles of 0.1 to 2.0 μm in diameter are especially active as condensers of cloud nuclei.

The effects of wind speed on concentration of particulates are very complicated, as described below: (1) increasing wind speed decreases buoyant plume rise and thereby increases ground-level concentrations; (2) increasing wind speed increases dilution and thereby decreases concentrations (Hdzworth, 1974); (3) increasing wind speed increases the resuspension of dust and thereby increases concentrations; and (4) a too strong wind can cause a funnel effect in canyon-like streets, and this may concentrate air pollutants locally by lifting street dust and fumigating emissions from elevated sources (Munn, 1975). Therefore, it is difficult to predict the influence of wind speed.

Mixing-depth is defined as the top of a ground surface-based layer in which turbulance and vertical mixing is relatively vigorous and in which the necessary lapse rate is approximately dry adiabatic. In the case of a ground-based inversion or of a relatively stable air, the mixing depth does not exist and vertical turbulance is either low or nil, therefore, emitted pollutants may stay or disperse in a thin layer. An extremely high concentration of pollutants may be detected in such situations. If the air becomes unstable and the mixing depth is high, the pollutants may be dispersed in a larger space and the concentration may be reduced. Therefore, the mixing depth is an important parameter in atmospheric dispersion (Holzworth, 1974).

In the studies of the implications of the meteorological parameters on particulate pollution, we ought to be interested not only in the physical process of these meteorological parameters, but also in the relationships that permit conclusions or even models to be drawn from air quality observations.

Therefore, empirical or statistical procedures are introduced and numerous empirical models are developed for describing the relationships between the various meteorological conditions and pollution levels. For example, Kleinman et al. (1974) observed in New York an inverse relationship between the concentration of suspended particulate matter and a "dispersion factor", defined as the product of mixing depth and the surface wind speed. This indicates that, in New York, TSP concentration is mainly determined by local meteorological parameters responsible for dispersion or dilution. On the other hand, it has been shown that in Albany, U.S.A. (Samson et al., 1975) and in Copenhagen, Denmark (Buch, 1977), the long-range transport of suspended particulates from remote source areas is predominant. An increased TSP concentration is observed at the measuring point when good diffusion conditions (such as high wind speed and atmopsheric instability) are prevalent.

In a tropical region, where there are no strong winds and heavy rainfall predominates, Trindade et al. (1980) also observed in Rio De Janeiro, aside from high negative correlation coefficients between TSP and the dispersion factor, there is also a strong inverse correlation between TSP and rain frequency. Moreover, the dispersion factors were used as normalizing factors in their study, to calculate "corrected TSP" concentrations which should represent TSP concentrations for constant meteorological conditions. An almost constant "corrected TSP" value was found over the two year period for Sao Cristovas.

In their observations of the effects of wind speeds, Marsh and Foster (1967) suggested that pollutant concentrations vary universely as the fifth root of the wind speed. In the Leicester survey (British Government, 1945), it was found that the pollutant concentrations varied inversely as the square root of the wind speed.

The above literature reviews show that various or even contrary conclusions concerning the effects of meteorological parameters are drawn, but this is not surprising, since statistical procedures are based on a group of observations at the given places and within given period of time, and the conclusions may have only local significance. They are strongly influenced by local conditions, by source-receptor relationships and by micrometeorological conditions. A high degree of generalization would usually not be achieved in such an approach.

2.6 The instruments for measuring particulates

A wide variety of analytical instruments are available for measuring particulate matter in the ambient air. They include the high volume air sampler, nephelometer, condensation nuclei counter, electrostatic charger, accoustic counter, electrostatic precipitator, thermal precipitator, impaction and impingement (United Nations, 1979). The high volume air sampler is commonly used for it is easily handled in field surveying and is suitable for quantitative analysis (Giever, 1976). The Environmental Protection Agency (1971) also reported that after particulate samples are collected on the filters, mass weighing, chemical analysis, particle identification and sizing can be made available for further studies. Therefore, in this study, only the Hi-Vol method is employed and will be discussed.

Filters are utilized as a collecting medium in Hi-Vol sampling, therefore, for an accurate sampling, the selection of the filter medium must be proceded by careful review of its characteristics, limitations and its relation to sampling requirements. The emphasis is laid upon the discussion on this respect.

Many different types of filters are available commercially. They can be broadly classified into the cellulose fiber filter, glass fiber filter, polystyrene filter and the membrane filter.

The cellulose fiber filters now used in air sampling were initially developed for other applications, e.g. low ash content and high purity for wet chemistry. They have the disadvantages of relatively low efficiency for collecting small particles, high flow resistance, and extreme sensitivity to moisture (Giever, 1976).

The National Air Sampling Network, maintained by the U.S. EPA for the measurement of atmospheric pollutants, makes use of a standard high-efficiency glass fiber filters for the sampling of aerosols. Glass fiber filters are less hygroscopic than paper filters and can withstand higher temperatures. They can be extracted with benzene, water, and acid for subsequent chemical analysis. However, a continuing problem has been the variability in their properties resulting from difficulties in quality control during the manufacturing process (Friedlander, 1977).

John et al. (1978) measured the filtration efficiency for submicrometer particles for several filter types. They reported that the nuclepore and cellulose (Whatman 41) are observed with fairly high penetration efficiency, in contrast to glass fiber filters, which detected no particle penetration. The lower limits of filtration efficiency ranged from 99.0 to 99.9%.

Neustadter (1975) pointed out that though many articles indicate that while the aerosol size decreases to submicron size, glass fiber filter shows better than 99% collection efficiency, and the collection efficiency of the W41 filter is degraded to as low as 70-85%, yet these are merely based on severe tests designed to rare absolute filters under laboratory conditions over limited time intervals. They held an actual 24-hours field test which compared W41 filters to vary efficient (99%) polystyrene filters. The results showed that little or no difference could be seen in collection efficiency with a sampling period longer than a few hours. They also set an experiment to test the feasibility of using W41 filter media to replace the glass fiber filter on a routine TSP (Hi-Vol) monitoring network with a sampling period longer than a few hours. Samples collected by glass fiber filters and W41 filters were compared with the analysis of various procedures. The results indicated that suspended particulate samples from glass fiber filters averaged slightly but not significantly higher than those from W41 filters.

Dams (1972) reported the results of a test of ten filter materials for suitability for atmospheric particulate sampling and elemental analysis. Of the commercially available filters tested, W41 cellulose has the lowest analytical blanks but may clog during prolonged smapling. For some elements, millipore membrane filters have low blanks but tend to disintegrate. Special polystyrene fiber filters may have low blanks and excellent particle retentivity but are fragile. Otherwise, the membrane filters due to a high pressure drop, cannot be used when high flow rate is required.

Glass fiber filters have low pressure drops, and high collection coefficients even for submicron aerosols, but they are generally unacceptable for analytical work because of their highly variated chemical compositions. Dams indicated that of commercial available filters, Whatman 41 is optimum from the standpoints of low blanks, particle retentivity, and ease of handling.

Kometani (1972) reported that during dry ashing of particulate matter on glass filber filter metals would show high losses. This is due to the formation of insoluble metal silicates since the metals react with glass at high temperatures, but the particulate on paper filters can be dry ashed safely at 500°C without significant volatization losses.

To avoid errors in weighing paper filter due to its sensitivity to moisture, Strand et al. (1978) made a constant relative humidity - temperature champer (50±3% for relative humidity and 25±0.5^{o}C for the temperature). Before tare weighing, all filters were equilibrated inside the champer for 24-hours. After sampling the gross weight determinations were again made after 24-hour equilibration in the champer. Repeated measurements resulted in weighings with less than 1% precision. Strand et al. also pointed that the poorer precision for the Whatman 41 filter weighing is probably due to irreversible water absorption by the cellulose group.

Wilson (1973) presented that the smaller filtration efficient for submicron aerosols for Whatman 41 filters is caused by the rather coarse fibers (about 20 μm width) of irregular section with twists and convolutions, and numerous pinholes of about 30 μm diameter through the paper.

Dams and Heindrycks (1973) reported that the use of cellulose filters in Hi-Vol air smapling requires a more powerful cooling system for the vacuum pump than does the use of conventional glass fiber filters. They indicated that if the turbine pump (used by the National Air Sampling Network of the United States) is used with glass fiber filters, for which the pressure drop increases only slowly with dust loading, a high flowrate can be maintained during the entire sampling and the pump is adequately cooled by the filtered air. With cellulose filters, however, the pressure drop increases rapidly during sampling, the pump which is cooled by the filtered air may overheat and burn out as the flowrate decreases rapidly. In order to avoid pump failure problems for samplings which are longer than a few hours, using a more powerful carbon-vane votary pump is introduced. Because this heavy duty pump has separate air cooling, it can operate continuously throughout the sampling.

Dams and Heindrycks also indicated that while using the cellulose filter in Hi-Vol air sampling, the filter may become rapidly clogged as the dust load increases, thus, the pressure drop increases rapidly during sampling, and consequently the flowrate may decrease by as much as 1/5 in 24 hours. Since the reduction of the flowrate is not linear with time, precise calculations of total air sample volumes require that readings be taken regularly during the sampling period. A simpler alternative is to empirically determine the weighing factors for initial and final flowrates. The weighing factors can be obtained in field experiments.

2.7 Previous studies in Hong Kong

A number of studies dealing with atmospheric pollution have been done in Hong Kong, but most of them are directed toward gaseous pollutants, especially the sulfur dioxide. The studies of present status of particulate pollution are not sufficient. However, some literatures is available and is discussed below.

Kwong (1978) used the Hi-Vol air samplers to collect the suspended particulates and analysed chemical compositions by means of reacter neutrons and Gamma-ray spectrometer. His study is less concerned with meteorological parameters and neglects the variation in concentration of particulates in different land use areas.

Yuen, S.T. et al. (1982) gave an interim report for the air quality studies in Junk Bay, which is a new town under development. They indicated that the mean TSP level ranges from 70 to 78 $\mu g/m^3$, and the maximum daily value during the sampling period is 140 $\mu g/m^3$, which though higher than would be expected in a rural environment, is not of serious concern.

EPA (1982) gave report for the study of air pollution from road traffic. Two monitoring surveys were conducted at Queensway and Central at sites considered as typical for pedestrian exposure. The roadside TSP levels ranged from 285 $\mu g/m^3$ to 495 $\mu g/m^3$, with an overall average of 372 $\mu g/m^3$ at Queensway, and from 173 $\mu g/m^3$ to 851 $\mu g/m^3$ with an overall average of 449 $\mu g/m^3$ at Ice House Street. The airborne Pb concentration range from 1.87 $\mu g/m^3$ to 5.64 $\mu g/m^3$ at Queensway and from 1.66 $\mu g/m^3$ to 3.17 $\mu g/m^3$ at Ice House Street. The mean values were 3.69 $\mu g/m^3$ and 2.53 $\mu g/m^3$ respectively. These values are of concern, however, they are similar to road-side measurements in other parts of the world.

CHAPTER III

METHODOLOGY

The theme of this study include three parts: (1) determination of the present status of particulate pollution in Hong Kong; (2) an assessment of the spatial and vertical variations of the particulate pollution; and (3) an evaluation of the correlation between the meteorological parameters and particulate pollution levels.

In the first part of the study, a general description is given of the pollution levels with respect to the mass concentration and chemical composition of the total suspended particulates. Instrumental analyses are employed in field and laboratory work.

In the second part of the study, an attempt is made to find out whether spatial and vertical land use patterns may lead to the variability of the particulate pollution in Hong Kong. The study tries to compare, (1) the difference between the data from roof and ground level ambient air, (2) the differences among the data in various land use areas.

The third part of the study attempts to determine the implications of the meteorological parameters on the particulate pollution, and to draw some conclusions or even generalizations from these implications.

In order to achieve the above aims, the following methods and procedures are proposed and used in the study.

3.1 Instrumentation

For collecting airborne suspended particulates in the ambient air, three Hi-Vol air samplers with W41 filters have been designed by the author and Dr. Sheng-I Hsu.

The sampler consists of two units: (1) the filter holder, (2) the assembling housing. Both are made of stainless aluminium and steel alloy. An aluminium roof is mounted above the sampler for protection from precipitation. Fig. 3.1 shows an exposed view of these parts.

There are many types of filter materials for air filtration. However, many studies indicated that if the filtration involves accurate elemental analysis for the filtered particulates and a Hi-Vol air for the sampling time above a few hours, the cellulose fiber filter may be comparatively acceptable (refer to 2.6). Thus, Whatman 41 filters are acceptable for Hi-Vol air filtration in this study.

The hygroscopic nature of cellulose fiber filters, however, can lead to unacceptable weighing errors (refer to 2.6). It is therefore imperative that conditions of constant temperature and humidity be maintained during tare and gross weighing. To overcome this problem, the air-conditioned environmental laboratory in the Geography Department of The Chinese University of Hong Kong, is taken as a clean, constant temperature and relative humidity environment (temp.: 23±3^{o}C, r.h.: 50±3%) for weighing operations. Before tare weighing and gross weighing, the filters are exposed in the environmental laboratory for 24 hours.

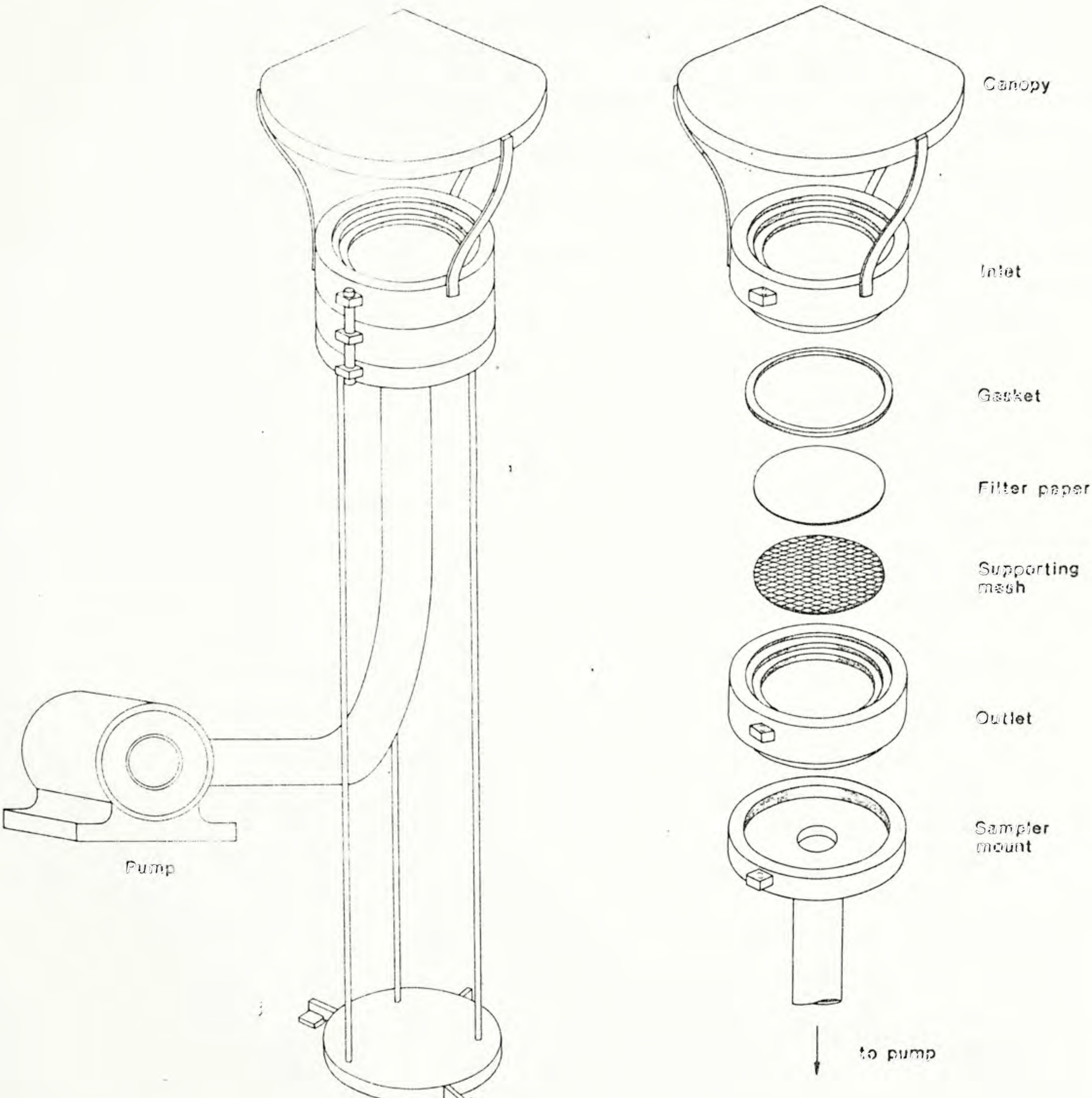

FIGURE 3.1 A HIGH VOLUME AIR SAMPLER (LEFT) AND ITS EXPLODED DIAGRAM (RIGHT).

As the samplings with W41 filters are covered for a period of time longer than a few hours, to avoid pumping failure (refer to 2.6), a more powerful vortex blower (Hitachi VB002S, Voltage 240) is used. This heavy-duty pump has separate air cooling and can operate continuously. Its free-air capacity is 1.1 m^3/min.

Facilities for physical and chemical analysis, such as electronic balance, atomic absorption spectrophotometer, are available in the Environmental Laboratory of the Geography Department of The Chinese University of Hong Kong.

3.2 Measuring of the mass concentration

To determine the mass concentration of the suspended particulates in the ambient air, the total volume of air sampled must be accurately estimated. However, as the flowrate may decrease rapidly during the sampling when W41 filter is used, the weighing factors for initial and final flowrate ought to be evaluated in the field for estimating the total volume of air sampled (refer to 2.6). The flowrate calibration curve and the weighing factor for each monitoring site can be seen in Appendix A.

T[illegible] mass of particulates collected on the filter was weighed by ele[illegible] balance. The weight of particulates was measured nearest [illegible] 10^{-4} g. Before tare weight and gross weight, the filters were [illegible]itioned in the Environmental Laboratory for 24 hours (refer [illegible]).

[illegible] concentration of suspended particulates in the ambient air ($\mu g/m^3$) can be computed by:

$$\frac{\text{mass of the collected particulates}}{\text{total volume of air sampled}}$$

3.3 The analysis of chemical compositions

The filter was first dry ashed at 500°C and then was mixed up with 10 ml nitric acid ($1HNO_3 + 3H_2O$) in the test tube. The mixture was digested in the sand bath and was boiled for about 1 hour. After digesting, the heavy metallic elements could be dissolved. The solution was refluxed with distilled water to access 50 ml in the 50 ml flask. Finally the solution could be loaded in a small bottle with a wide orifice for precipitation. This process required at least one day. The clarified solution could then be analyzed to find out the concentration of the heavy metallic elements which consisted of Cd, Cr, Cu, Fe, Mn, Pb, Zn, Ni by means of atomic absorption spectrophotometry.

Fifteen clean filters are also treated by the same procedures and the analytical results are taken as the blanks of the filters, which can be seen in Table 3.1. The net concentration for each element can be obtained by substracting the blank value of each element.

Since the element iron is commonly found in the earth crust and it is in quite a constant proportion in different continental areas, iron is selected as a reference element for calculating for enrichment factor of each element. The value of the enrichment factor can determine whether or not each element derives from

Table 3.1 The blanks of the W41 filters

Elements	Mean	Standard Deviation
Zn	10.19	±7.94
Fe	7.25	±2.61
Pb	4.38	±2.74
Cu	1.50	±0.61
Ni	1.25	±0.83
Mn	0.31	±0.14
Cd	0.31	±0.11
Cr	0.28	±0.14

Units: μg/g

anthropogenic sources.

$$\text{The Enrichment Factor } EF_{(x)} = \frac{X/Fe \text{ aerosols}}{X/Fe \text{ crust}}$$

where X = a certain element

aerosols = the aerosols in the atmosphere

crust = the earth crust

If the EF of a certain element in the airborne suspended particulates is approximately equal to 1 or below 1, it is believed that this element mainly comes from natural sources. If the EF is highly greater than 1, it can be assumed that for the most part the existence of this element in the atmosphere is the result of emissions from the anthropogenic sources.

3.4 The spatial variation of pollution levels

For spatial comparison of pollution levels, it is necessary that inferential statistics be employed in order to make generalizations for a population based on a data sample. Therefore, the following gives a description of the sampling procedures, and then a hypothesis test based on this data sample.

(i) Data Sampling

Due to limitations of available manpower and resources, the collection period of the air samples commenced from 15th July, 1982 and ended on 15th January, 1983.

Air samplers were used at five sites representing the nonurban area, the industrial area, the commercial-residential area, the industrial-residential area, and the high-class residential area. The selected locations for these sampling sites are described as followings:

(1) Nonurban area: The meteorological station of The Chinese University of Hong Kong. It is less populated and located at a distance from the industrial and the densely populated urban areas.

(2) Industrial area: The Hoover Industrial Building in Kwai Chung District is selected. There are many multi-storey industrial buildings consisting of textile factories, dyeing factories, metal factories, plastic factories, electronic factories, etc. in this area.

(3) Commercial-residential area: The sampler is sited at Tak Ming Middle School in Shum Shui Po District. It is the one of the most densed population area in Hong Kong. At the ground floor and the lower floors of buildings in this area, there are many cafe shops and restaurants, from which the solid and liquid particles are emitted.

(4) Industrial-residential area: The sampler was sited at Shun King Building in Tai Kok Tsui District. Liang (1972) indicated that in this district, there are local business services, factories and industrial equipment shops, dominated at the ground floor. From first floor to top floor, residential and industrial (mainly small factories) land use dominates.

(5) High-class residential area: The sampler was sited at the top floor (2nd floor) of Kowloon Tong Middle School in Kowloon Tong District.

With the exception of the nonurban area and high-class residential areas, the samplers sited at the other three areas are located less than 40 meters from the main road. The sampling locations are indicated in Figure 3.2.

A total of thirty-five days were randomly selected within the field work period at each sampling site. The high-volume air sampler was sited 1.40 m above the ground or on the balcony of the 1st floor of the buildings. The sampler at the campus of C.U.H.K. can be operated on any testing (measuring) day for comparison.

(b) Analysis of Variance

In order to evaluate the spatial variability of the pollution level, oneway analysis of variance method is employed for comparison. Here, the observed variability in the sampling data is subdivided into the variability between areas and the variability within area. The former can be considered as real differences among the land use areas, the latter can be considered as the day-to-day variability or the variability by chance within a land use area. The null hypothesis is that there is no difference of pollution level among land use areas. To test it the following statistic is calculated:

$$F = \frac{\text{Variance between areas}}{\text{Variance within areas}}$$

The greater the F statistics, the greater the difference of the pollution level among the land use areas. In this study, the significance level is 0.05, if the observed significance level is smaller than 0.05, the null hypothesis is rejected.

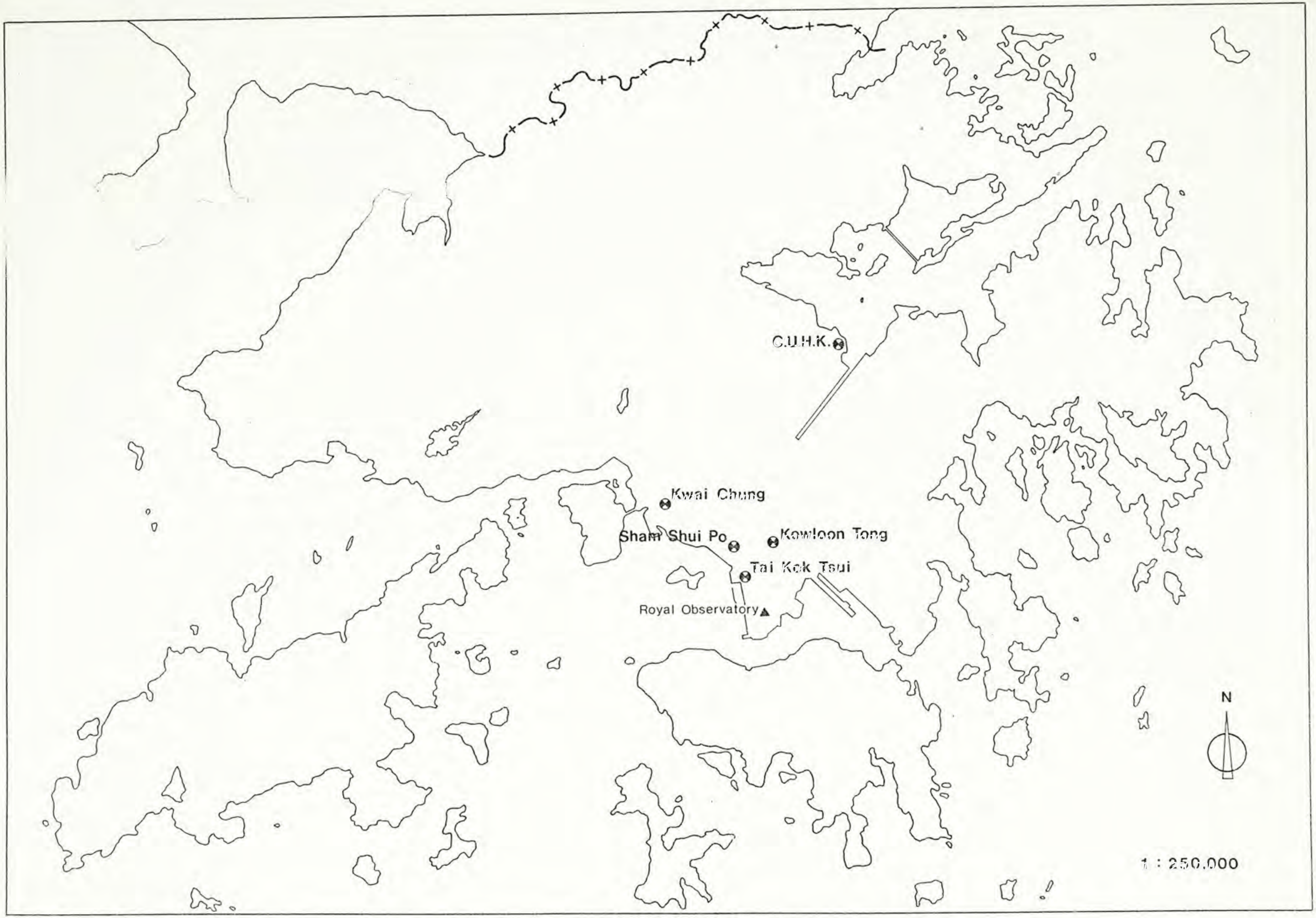

Figure 3.2 The locations of the monitoring sites.

(c) Scheffe test

In an analysis of variance, the rejection of the null hypothesis means that the means of pollution levels at different land use areas are not equal, but it does not show which means are significantly different from each other, since an extreme value of a mean may enlarge the variability among the whole means. Therefore, a variety of special techniques known as multiple comparison procedures are available for determining which means are different from each other. These procedures set up more stringent criteria for declaring significance than those of the usual T-test. The difference between two sample means must be large enough so as to be identified as a true difference.

As the group size of samples at different land use areas are not equal, the Scheffe test shown by Scheffe (1953) is adopted. The significance level of differences between the pairs of areas is also 0.05.

If the means of pollution level at different land use areas are equal at 0.05 significance level, the samples of these areas may be grouped into a subset, which is called the homogenous subset.

3.5 The comparison between the ground-level and roof-level particulate pollution

At the sampling [illegible] described above, such as Kwai Chung District, Tai Kok Tsui District and Shum Shui Po District, one Hi-Vol sampler was set on [illegible] balcony of the 1st floor, and another one was set on the roof of the building. The two samplers were operated simultaneously on ten randomly selected days in order to study the effect of height on the concentration of the suspended particulates.

For comparing the particulate pollution between roof-level and ground-level of a building, the paired T-test method is employed. As the samplers were operated simultaneously on the same day; the samples are called paired samples. In such a paired T-test, the day-to-day variability therefore has substantially less effect on comparisons between the roof-level and the ground-level and, the linear correlation on the particulate pollution level between the top-floor and ground floor can also be calculated from the paired values.

The null hypothesis is that there is no difference of the pollution levels between the roof-level and the ground-level ambient air. The significance level is 0.05. The observed significance level can be calculated to values of T-distribution of N degree of freedom. If the type one error is less than 0.05, the null hypothesis is rejected.

3.6 The implication of meteorological parameters on the particulate pollution

In this study, multiple regression analysis is the method employed to investigate the relationships between the particulate pollution and the meteorological parameters, and the Two-sample T-test to further evaluate the wind speed effect on the dispersion of the particulates in the urban areas. The procedures of these methods are discussed as the following:

(a) Multiple regression

To investigate the relationship between the particulate pollution and the meteorological parameters, many weather parameters can be used as independent variables to predict the variability of the particulate pollution level (dependent variable) in the regression equation. However, in this study, only the amount of precipitation, average wind speed, and maximum mixing depth are taken as the independent variables since they are the most important dispersion or removing factors for the suspended particulates in the atmosphere.

The maximum mixing depth is usually calculated with the aid of a early morning temperature sounding. On a chart of height or pressure versus temperature showing the latest sounding, the maximum surface temperature in the afternoon is used to construct a dry-adiabatic process curve up to the height at which the environmental temperature sounding is intersected. The point of intersection defines the thickness of the convective layer. In this study, the 0800 Hong Kong time sounding is taken as the reference sounding, and the daily maximum temperature recorded at the Royal Observatory at Tsim Sha Tsui is applied to construct a dry-adiabatic process curve.

The values of the daily amount of precipitation measured at the weather station of C.U.H.K. is employed for the analysis of the monitoring site of C.U.H.K. However, the values of the daily amount of precipitation and the daily average wind speed measured at the Royal Observatory are employed for the analysis of the other monitoring sites.

Multiple regression analysis is based on the assumed condition that the variation of an element is a linear function of the combined variations of multi-elements. Therefore, the variation of this dependent element can be predicted by evaluating this multi-variable linear function.

The multiple regression procedures may be categorized as descriptive statistics, as it is used:

(1) to find the best linear prediction equation and evaluate its predictive accuracy; (2) to control for other confounding factors in order to evaluate the contribution of a specific variable or set of variables; and (3) to find structural relations and provide explanations for seemingly complex multivariate relationships. To achieve these descriptive aims, the following parameters derived from many computing and testing procedures are employed in this study.

The coefficient B is called the partial regression coefficient, which measures the rate of increase of Y with increasing X_i, with X_2 ... X_K constant at their mean values.

The Beta are called the standardized partial regression coefficient, which can act as indicators of the relative importance of the independent variables to explain the dependent variable (Y), as the variables are expressed in standardized (Z score) form.

While the proportion of variance of Y explained by combined linear influence of the independent variables, i.e. the goodness of fit of the regression equation can be evaluated by examining the square of the multiple correlation (R^2). And, the multiple correlation coefficient (R) measures the intensity of the linear relationship between the dependent variables and the group of predictors (x_i).

Another way of assessing the relative importance of independent variables is to consider the increase in R^2 when a variable is entered into the equation that already contains the other independent variables. A large change in R^2 (R^2 change) indicates that a variable provides unique information about the dependent variable that is not available from the other independent variables in the equation. The signed square root of the increase is called the part correlation coefficient.

Regression analysis is commonly performed on sample data which is concerned with generalizing to a population. In this study however, it will deal only with the three most commonly used hypothesis testing procedures, namely (1) the "overall" test for goodness of fit of the regression equation; (2) the test for a specific regression coefficient; (3) the test for a subset of regression coefficients.

The null hypothesis of the overall test is that the multiple correlation is zero in the population from which the sample was drawn. The test statistic employed for the overall test is:

$$F = \frac{\text{variance due to regression (explained proportion)}}{\text{variance due to residuals (unexplained proportion)}}$$

The higher the F value, the more significant of the whole model is. The observed significance level can be obtained by comparing to value of F distribution table.

In the above test procedure, the acceptance of the alternative hypothesis may lead to the conclusion that one or more regression coefficients have a value greater than zero, but it cannot indicate which specific i values are nonzero. Therefore, a test of a null hypothesis that a specific regression coefficient is equal to zero is needed. The test statistic is:

$$F = \frac{\text{incremental variance due to } x_i}{\text{variance due to residuals}}$$

If the observed significance level is greater than an appointed level, the null hypothesis is accepted and the specific variable is unsignificant in this model.

To determine which set of variables are significant for explaining the variation of Y in the model, a statistical procedure identified as stepwise selection is employed. The selection of pairs is a step-by-step procedure, during which the higher the partial regression coefficient of the variables, the former the variables be entered to create the new regression equations. The F-test is again employed one after another to determine whether the new equation is significant.

$$F = \frac{\text{incremental variance due to } x_1, x_2, \ldots, \text{ and } x_{i-1}}{\text{variance due to residuals}}$$

The procedure will not stop until either all variables are entered in the equation, or the group of 1 ... i independent variables is not significant to explain variability of Y while ith variable entering in the equation. The set of significant independent variables is said to be "the variables in the equation", the other variables are said to be "the variables not in the equation".

(b) Two-sample T-test

Wind speed is probably the single most useful indicator of general atmospheric dispersion conditions. Where the concern is about city-wide pollution due to numerous emissions throughout the area, later on the number of days with the average wind speed less than some specified value may be more useful. It is expected that under calm wind conditions, the pollutants may be easily damped at the lower layer of atmosphere. The critical wind speed associated with a build-up of pollution in cities is often considered to be below 3 m/s (6 knots/hr), (Holzworth, 1974).

In considering whether there is evidence that the build-up of pollution in the city is associated with wind speed below 6 knots/hr., the two-sample T-test is employed. In this statistical procedure, the mass concentration of particulates at all sampling days are divided into two groups. The grouping criteria based on the daily average wind speed. Group 1 is the set of days for which the daily average wind speed is greater than or equal to 6 knots/hr., group 2 is that below 6 knots/hr. The null hypothesis is that there is no difference between the means of the concentration of particulates between two grouped sampling days.

The significance level is 0.1. The observed significance level T can be computed by comparing to the value of T distribution table.

Only the samples from monitoring sites of Kwai Chung, Tai Kok Tsui and Sham Shui Po are selected to be tested, as they are sited in the urban areas.

3.7 Data computing

All the raw data are processed and stored in magnetic disks. These data are computerized and analysed in the Computer Service Center of C.U.H.K. There are many valuable computer programmes ready for use in the center. In this study, the programmes of "Statistical package for Social Sciences" (SPSS) are employed.

CHAPTER IV

SPATIAL DISTRIBUTION OF THE PARTICULATE POLLUTION

4.1 Introduction

Two basic aspects of investigation are needed to evaluate the spatial distribution of particulate pollution in Hong Kong. These include the studies in (a) present status of particulate pollution, and (b) the spatial variability of the particulate pollution. In this section, the status of particulate pollution in various land use areas will be discussed. Through the analysis of variance and the Scheffe's test methods, the spatial variability of the particulate pollution may be revealed.

4.2 The mass concentration

The mass concentration of the TSP is the most important indicator for the study of particulate pollution. Its quantity is indicative of the natural and anthropogenic sources nearby, and the conditions of the transportation and dispersion capacity of the atmosphere.

The primary standard and secondary standard for suspended particulates provided by U.S. EPA are applied to classify the particulate pollution level at each monitoring day. Therefore, the day in which the daily average concentration is below 150 $\mu g/m^3$ is defined as a "clean day", that from 150 $\mu g/m^3$ to 260 $\mu g/m^3$, a "normal day", and that above 260 μg/m^3, a "polluted day". The frequency percentage of "polluted", "normal", and "clean" air over the five land use areas is given in Figure 4.1.

The mean level at the campus of C.U.H.K. is 66.78 μg/m^3 (see Table 4.1). This level is considerably higher than would be expected of a rural environment, but it is not surprising due to the reclamation construction in the Tolo Harbour and the railway electricity construction in process to the east about 200 m from the monitoring site; and on every school day, there are 144 meet-class buses passing by the road 5 m nearby the sampler, in addition to many heavy lorries passing by for nearby public construction as well as building construction on the campus of the University. Moreover, Tai Po Road, which is a high vehicle volume road linking the Kowloon urban area and the northern part of N.T., winds along the western fringe of the campus. The latter influence is supported by further examination of the Pb concentration described in 4.2.

The minimum levels were recorded at two consecutive sampling days (29 December, 1982 and 30 December, 1982). The levels are 7.0 μg/m^3 and 8.8 μg/m^3 respectively. After a full scan of the meteorological parameters, it was found that the rainfall in those days were of 71.7 mm per day and 20 mm per day respectively. The high volume of rainfall may have a great effect on the concentration of the TSP. For a detailed description, please see Chapter 6.

The maximum level is 145.0 μg/m^3, but it is not a serious matter, since it is well within the U.S. EPA primary standard of 260 μg/m^3, and secondary standard of 150 μg/m^3 as a 24 hour

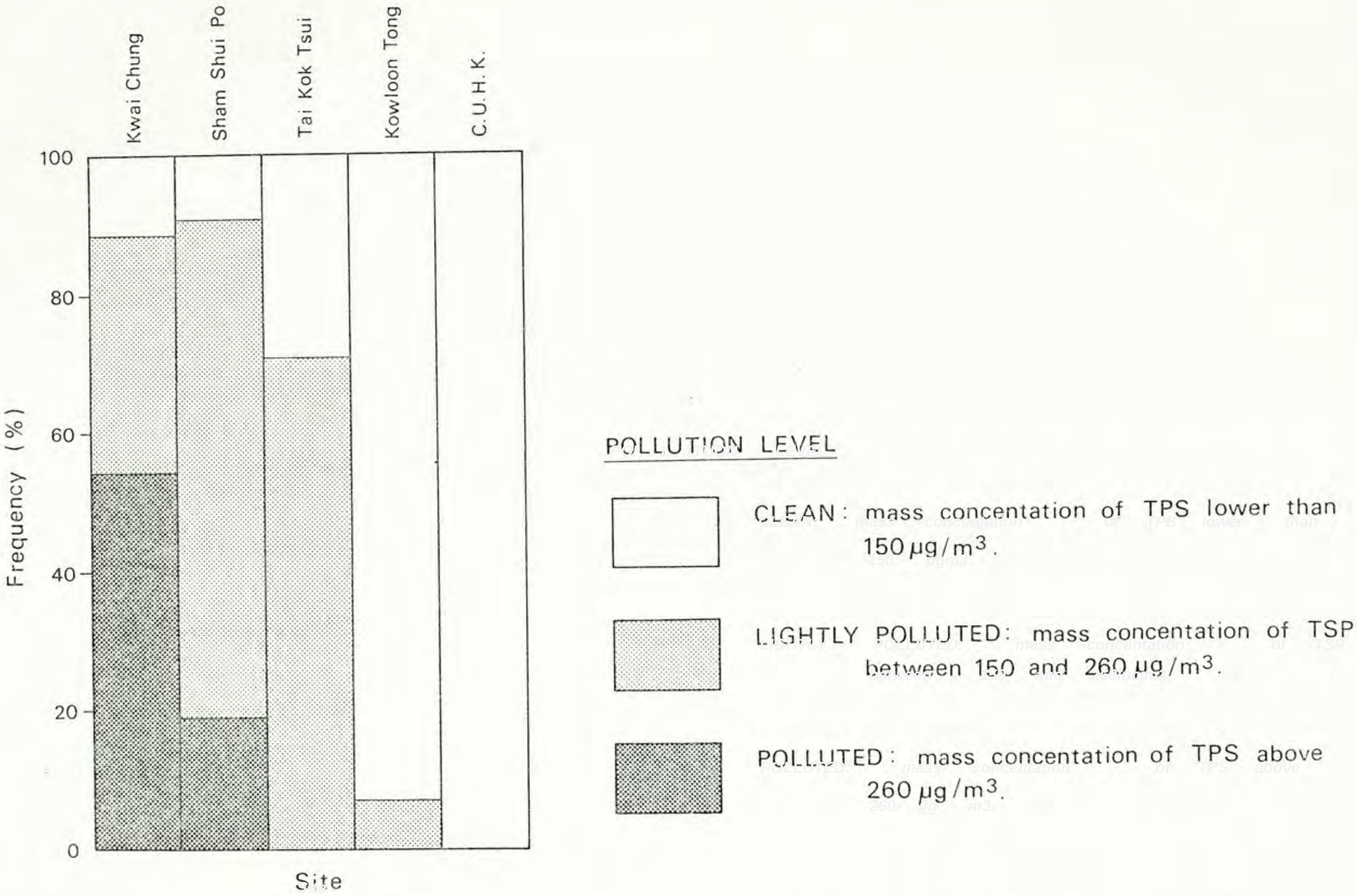

Figure 4.1 The frequency of pollution levels at the five land-use areas.

Table 4.1 The summary of the pollution level of total suspended particulates at five land-use areas in H.K.

Sampling Site	C.U.H.K.	Kwai Chung	Sham Shui Po	Tai Kok Tsui	Kowloon Tong	Total
No. of samples	92	37	37	39	30	235
Mean	66.78	277.92	224.48	163.24	88.32	143.61
Standard deviation	31.42	76.14	54.62	37.10	38.52	143.61
Min.	7.0	111.10	110.0	84.2	28.7	7.0
Max.	145.0	478.9	328.7	244.5	208.9	478.9

Units: $\mu g/m^3$

average. The particulate pollution level of all sampling days can be considered as "clean day".

Kowloon Tong is a high-class residential district (Liang, 1972). Within the district, there is low traffic volume, no industrial activities, fewer food and drink services and low population density. The mean level is 38.3 $\mu g/m^3$. The maximum level is 208.9 $\mu g/m^3$ (see Table 4.1), and the TSP level of 7% sampling days are higher than 150 $\mu g/m^3$ (secondary standard). According to the primary standards of ambient air quality provided by U.S. EPA, these levels show that the Kowloon Tong District should be considered for a less polluted area.

Liang (1972) classified Tai Kok Tsui District as a residential-industrial district. In this district, the small-scale industrial land use dominates at the ground floor, whereas the upper floors are used for residential as well as industrial purposes. It is a less dense land use pattern then in other metropolitan areas. However, due to limitations of the available sampling site, the sampler was sited at the fringe of this district and is comparatively closer to the densely populated residential area to the northeast. At the southwest, 150 m from the monitoring site, there are many wholesale metal, electical and building equipment shops distributed along the Canton Road and Tong Mei Road. Otherwise, the sampling site is 40 m north from the seashore, and the quite clean sea breeze might dilute the concentration of TSP in the air. Therefore, it is believed that the sampling results are lower than that of the ambient air quality of this industrial-residential area. The mean level of the TSP pollution is 163.2 $\mu g/m^3$. The maximum level is 244.5 $\mu g/m^3$ which is still below the U.S. EPA primary standard. In addition, the particulate pollution level of 71% of the sampling days are considered as the "lightly polluted days".

Sham Shui Po District is a typical commercial-residential district (Liang, 1972). At the ground floor the retail business and service business area dominates, and, above the ground floor, the residential land use is dominated. The Hong Kong 1981 population census showed that the population of this district is the densest in Hong Kong. Thus, the ambient air quality of this district ought to be most alarming. The monitoring site is considered to be quite representation of the commercial-residential area, because it is quite separate from two main roads; and within 50 m distance, there are many restaurants and cooked food stalls (see Appendix B), which are common features in this district. Therefore, the level of samples represented can be taken as the ground ambient air quality of this district. The mean level is 224.4 $\mu g/m^3$ and the maximum level is 328.7 $\mu g/m^3$, which are above the primary standards. Among the whole 37 sampling days there were 8 days (24%) with records above this standard and 68% of the sampling days with records between 150 $\mu g/m^3$ and 260 $\mu g/m^3$. This is cause for concern since the dwellers living in these conditions for a long time may suffer.

Kwai Chung is an industrial land use area. This district mainly consists of many multi-storey industrial buildings in which the textile factories, dying mills, garment factories, electronic and electrical engineering factories, metalworks, plastic factories, toy factories and printing factories are common. The maximum level of the samples is 478.9 $\mu g/m^3$ (see Table 4.1), which is far above the primary standard. Out of the total 37 samples, 23 (55%) samples are of the levels above the primary standard and 33% of the sampling days with records between 150 $\mu g/m^3$ and 260 $\mu g/m^3$. It is believed that the ambient air quality at the ground-level in this industrial area is poor. Based on the field survey, the high particulate pollution level seems to be the combined effects of the following:

(a) a large amount of soot and resuspended particles derived by the high volume of traffic within and around the industrial area (see Table 4.2);

(b) numerous waste gases and solid materials emitted directly through the windows at the lower floors;

(c) ventilation conditions are poor due to the congestion and the extreme height of the buildings relative to the width of the roads.

For determining the differences in mass concentrations of TSP in five land use areas, an analysis of variance method is employed. The between areas mean square is 389808, and the within areas mean square is 2179, thus the F value is 178.84, and an observed significance level of 0.0000 is obtained by a comparison to the F distribution table with 4 and 230 degrees of freedom. As the observed significance level is small, the alternative hypothesis that the means of mass concentration of TSP in the five land use areas are not equal is accepted.

Table 4.2 The Scheffe test for comparison of the mass concentration of TSP in five land-use areas

S^2 = ranges for the 0.050 level = 4.39 $\hat{V}$ [H] = 33.0125 Homogenous Subsets				
Subset 1			Subset 2	
Area	C.U.H.K.	Kowloon Tong	Area	Tai Kok Tsui
Mean	66.7	88.3	Mean	163.2
Subset 3			Subset 4	
Area	Sham Shui Po		Area	Kwai Chung
Mean	224.2		Mean	277.9

$\hat{V}$ [H] = the estimated variance of the contrasts

Homogenous subset = in which the mass concentration of TSP in the land-use areas are not significantly different from each other

In order to find out which sample means differ from each other, Scheffe's test is employed (refer to 3.4). Five area samples are multi-paired for comparison. If the mean concentrations of TSP at the sampling areas are not significantly different from each other, they are grouped into a subset, in which the sample mean do not more than the shortest significant range. Among them, the samples for C.U.H.K. and those for Kowloon Tong District are grouped in subset 1. This means that there is no significant difference in the mass concentration of TSP between the campus of C.U.H.K. and Kowloon Tong District at the significance level of 0.05. Otherwise, the other area means are significantly different from each other (see Table 4.2).

4.3 The chemical compositions

The chemical composition of TSP is also an important indicator in the study of particulate pollution. Usually it reflects the effects of nearby pollution sources, the nature of the land surface, and the physical and chemical reactions in the atmosphere. Special attention should be paid to toxic elements, because of their extremely dangerous effects on human life and the environment.

The chemical elements analyzed in this study are iron, copper, zinc, nickel, lead, manganese, cadmium and chronium. Owing to a careless laboratory process the concentration of chromium of the air samples at Tai Kok Tsui District was not analyzed.

The mean level and the maximum level of the concentration of airborne elements are highest at Kwai Chung District (see Table 4.3). The lowest levels are to be found at the campus of C.U.H.K. After a casual comparison of values of all sites, it is found that the concentration level are roughly proportional to the levels of mass concentration of TSP. Thus, it is believed that the more the pollution sources emit, the higher the mass concentrations of TSP and the concentration of chemical elements are in the case of Hong Kong.

In order to analyze the concentration of airborne elements, toxic elements should be given greater weight. Table 4.4 shows ambient air quality standards in various countries for four toxic heavy metals. By comparing the concentration of airborne elements with the ambient air quality standards, it was found that the concentrations of Mn and Cd at five land use areas are far below the various maximum permitted levels, but the concentrations of Pb are above those levels found in even the nonurban areas (C.U.H.K.). The maximum level of Cr at Kwai Chung District is 1.1655, which is slightly above permitted levels. It is not surprising that there are no serious large emission sources of Mn and Cd at all monitoring sites. The minute volumes may be attributed to natural sources or small-scale factories; moreover, the common features of high traffic-flow volume on the roads and congested traffic conditions may be the main contribution to the high level of Pb pollution in the ambient air in Hong Kong.

For analyzing the differences in the concentration of airborne

Table 4.3 The concentration of airborne elements at five land-use areas

Element	Concentration \ Site	C.U.H.K.	Kwai Chung	Sham Shui Po	Tai Kok Tsui	Kowloon Tong
Fe	Min.	0.15	1.37	0.80	1.12	1.11
	Mean	1.15	4.50	2.66	2.27	2.49
	Max.	3.84	10.87	5.57	4.64	6.30
Cu	Min.	ND	0.036	0.028	0.008	0.024
	Mean	0.019	0.262	0.084	0.064	0.053
	Max.	0.073	2.228	0.246	0.192	0.428
Zn	Min.	ND	0.29	0.05	0.08	0.13
	Mean	0.20	3.78	0.75	1.16	0.46
	Max.	2.24	20.18	2.02	6.06	2.09
Ni	Min.	ND	ND	ND	ND	ND
	Mean	0.011	0.063	0.021	0.020	0.016
	Max.	0.244	0.234	0.067	0.063	0.034
Pb	Min.	0.036	0.351	0.178	0.487	0.387
	Mean	0.665	2.794	0.798	0.822	0.729
	Max.	2.502	11.836	1.435	2.019	1.700
Mn	Min.	0.005	0.049	0.043	0.030	0.029
	Mean	0.039	0.181	0.119	0.119	0.093
	Max.	0.206	0.469	0.205	0.340	0.244
Cd	Min.	ND	ND	ND	ND	ND
	Mean	0.0010	0.0029	0.0023	0.0021	0.0014
	Max.	0.0056	0.0081	0.0063	0.0090	0.0091
Cr	Min.	ND	0.0058	ND	Not analysed	ND
	Mean	0.0037	0.0934	0.0127		0.0039
	Max.	0.0352	1.1655	0.0606		0.0171

Units: $\mu g/m^3$

ND : below detection limits

Table 4.4 National ambient air quality standards for some airborne elements

Substance	Country	Long-term standard	
		$\mu g/m^3$	Averaging time (hours)
Cadmium	Yugoslavia	0.003	24
Chromium	Romania	0.0015	24
	East Germany	0.001	24
	Israel	0.0015	24
	U.S.S.R.	0.0015	24
	Yugoslavia	0.0015	24
Lead	Bulgaria, Czechosolvakia, E. Germany, U.S.S.R., Yugoslavia	0.0007	24
	Hungary	0.001	24
	Israel	0.005	24
	Italy	0.01	8
	Poland	0.001	24
		0.0005	24
	Romania	0.001	24
Manganese	Bulgaria, Czechoslovakia, E. Germany, Yugoslavia, Israel, Romania, U.S.S.R.	0.01	24

Source: Newill (1976)

elements at five land use areas, the one-way analysis of variance is again adopted. The significance levels for those tests are 0.05. The results show that the variability between areas are much greater than the variability within areas, and the F probability is less than 0.0000 (see Table 4.5). Therefore, for each element, the null hypothesis that the means of the concentration level in the ambient air at five land use areas are equal is not accepted.

Again, for finding out which concentration means in the five land use areas are different from each other, the Scheffe test is again adopted. The significance level is also 0.05. The ranges of the Scheffe procedure for all elements except Cr are 4.39, but, for Cr, as the number of areas being contrasted is just 4, and the degree of freedom of total samples is 160, so the range for the Scheffe procedure for Cr is 4.00. The mean concentration of each element at five land use areas are multi-pairwise compared and the mean concentrations, if not significantly different, are grouped into subsets. The mean concentrations are ordered from smallest to largest, thus arranging the areas in the order shown in Table 4.6.

For all elements except Cd, the mean concentrations of TSP at Kwai Chung District are excluded from other subsets, since the mean concentrations for each element are significantly higher than those in other areas. At the monitoring site of C.U.H.K., the mean concentrations of Mn and Fe are excluded from other subsets. This means that the mean concentrations of Mn and Fe at C.U.H.K. is significantly less than those at other areas.

Table 4.5 The analysis of variance for comparison of the concentration of various airborne elements at five land-use areas

		D.F.	Sum of Square	Mean Square	F Ratio	F Prob.
Fe	Between Groups	4	292.4	73.1	43.798	0.00
	Within Groups	222	370.5	1.6		
	Total	226	662.9			
Cu	Between Groups	4	1.55	0.3875	18.143	0.00
	Within Groups	222	4.74	0.0214		
	Total	226	6.29			
Zn	Between Groups	4	343.33	85.8	26.452	0.00
	Within Groups	222	720.36	3.2		
	Total	226	1063.69			
Ni	Between Groups	4	0.071	0.0179	21.483	0.00
	Within Groups	222	0.184	0.0008		
	Total	226	0.256			
Pb	Between Groups	4	129.53	32.38	22.990	0.00
	Within Groups	222	312.71	1.41		
	Total	226	442.25			
Mn	Between Groups	4	0.579	0.1449	39.778	0.00
	Within Groups	222	0.808	0.0036		
	Total	226	1.388			
Cd	Between Groups	4	0.0001	0.00	10.192	0.00
	Within Groups	222	0.0006	0.00		
	Total	226	0.0008			
Cr	Between Groups	3	0.215	0.0717	8.549	0.00
	Within Groups	183	1.342	0.0084		
	Total	188	1.557			

For the elements of Cr, Pb, Cu, Zn and Ni, the mean concentrations of these elements at C.U.H.K., Kowloon Tong District, Sham Shui Po District and Tai Kok Tsui District are grouped into a subset. These mean concentrations of such airborne elements are not significantly different from each other at the 0.05 significance level.

For the Cd, the mean concentration at C.U.H.K. and Kowloon Tong District are grouped in subset 1. However, the mean concentration at Kowloon Tong District and Sham Shui Po District in subset 2. In subset 3, the mean concentration at Tai Kok Tsui District and Sham Shui Po District are regrouped with that at Kwai Chung District. The results show that on one hand, both concentrations of Cd at C.U.H.K. and Kowloon Tong District are not significantly different, and on the other hand, the concentration of Cd at Kowloon Tong District is also not significantly different from those of Tai Kok Tsui and Sham Shui Po. The concentration of Cd at Kwai Chung is not significantly different from those at Tai Kok Tsui and Sham Shui Po Districts.

Kran Lan (1971) illustrated the main sources of the airborne heavy metal pollutants. After a preliminary investigation of the situation of the pollution sources at each monitoring site, as tabulated at Appendix 3 the possible relations between sources and pollutants are shown. The numerous and varied types of factories within such a small sampling space at Kwai Chung District explains why the concentrations of all elements are at the highest level among those of other land use areas. Besides the high-traffic flow volume, numerous electroplating, metals and steel factories

Table 4.6 The Scheffe test for the comparison of the concentration of airborne elements at five land-use areas

Fe	$\hat{V}$ [H] = 0.9136				
	Homogenous Subsets				
	Subset 1				
	Area	C.U.H.K.			
	Mean	1.1593			
	Subset 2				
	Area	Tai Kok Tsui	Kowloon Tong	Sham Shui Po	
	Mean	2.2752	2.4983	2.6625	
	Subset 3				
	Area	Kwai Chung			
	Mean	4.5014			
Cu	$\hat{V}$ [H] = 0.1033				
	Homogenous Subsets				
	Subset 1				
	Area	C.U.H.K.	Kowloon Tong	Tai Kok Tsui	Sham Shui Po
	Mean	0.0195	0.0537	0.0647	0.0841
	Subset 2				
	Area	Kwai Chung			
	Mean	0.2629			
Zn	$\hat{V}$ [H] = 1.2737				
	Homogenous Subsets				
	Subset 1				
	Area	C.U.H.K.	Kowloon Tong	Sham Shui Po	Tai Kok Tsui
	Mean	0.2070	0.4681	0.7586	1.1687
	Subset 2				
	Area	Kwai Chung			
	Mean	3.7805			
Ni	$\hat{V}$ [H] = 0.0204				
	Homogenous Subsets				
	Subset 1				
	Area	C.U.H.K.	Kowloon Tong	Tai Kok Tsui	Sham Shui Po
	Mean	0.0119	0.0160	0.0205	0.0217
	Subset 2				
	Area	Kwai Chung			
	Mean	0.0636			

(to be continued)

Table 4.6 (cont'd)

Pb	$\hat{V}$ [H] = 0.8392 Homogenous Subsets Subset 1 Area C.U.H.K. Kowloon Tong Sham Shui Po Tai Kok Tsui Mean 0.6659 0.7294 0.7989 0.8228 Subset 2 Area Kwai Chung Mean 0.7940
Mn	$\hat{V}$ [H] = 0.0427 Homogenous Subsets Subset 1 Area C.U.H.K. Mean 0.0397 Subset 2 Area Kowloon Tong Tai Kok Tsui Sham Shui Po Mean 0.0936 0.1195 0.1198 Subset 3 Area Kwai Chung Mean 0.1818
Cd	$\hat{V}$ [H] = 0.0012 Homogenous Subsets Subset 1 Area C.U.H.K. Kowloon Tong Mean 0.0010 0.0014 Subset 2 Area Kowloon Tong Tai Kok Tsui Sham Shui Po Mean 0.0014 0.0021 0.0023 Subset 3 Area Tai Kok Tsui Sham Shui Po Kwai Chung Mean 0.0021 0.0023 0.0029
Cr	$\hat{V}$ [H] = 0.0648 Homogenous Subsets Subset 1 Area C.U.H.K. Kowloon Tong Sham Shui Po Mean 0.0037 0.0039 0.0127 Subset 2 Area Kwai Chung Mean 0.0934

(to be continued)

Table 4.6 (cont'd)

Note: for all elements except Cr, the ranges of the contrast (S^2) at 0.05 level is 4.39, for Cr, S^2 = 4.00

$\hat{V}$ [H] = estimated variance of the contrasts

Homogenous subsets = in which the concentration of airborne element at various land-use areas are not significantly different from each other are the main sources contributing the unusually high concentration of Pb and Cr in the ambient air.

The amounts of pollutant emitting sources within the sampling space at Tai Kok Tsui and Sham Shui Po districts do not differ greatly so the concentration level at the two monitoring sites are very similar. Besides, the sources are commonly found in most parts of the urban areas in Hong Kong, and the concentration levels of such elements may be regarded as the reference ambient air quality in the similar commercial-residential areas in Hong Kong.

There are 50 scheduled diesel trains, as well as 71 up-bound scheduled electric trains passing through Kowloon Tong District, with which come the Pb and soot. Aside from the pollutants derived from the traffic, there are no other significant pollution sources within the Kowloon Tong District, and the possible pollutants can be referred to as the effects of the transportation and diffusion process in the atmosphere from other polluted urban areas. Thus, the concentration levels of all elements are slightly lower than in the above mentioned districts in the urban areas.

The campus of The Chinese University of Hong Kong is situated in a nonurban area, and the Kowloon mountains which lie to the south of the campus act as a barrier between the campus and polluted urban areas. Except for the high Pb pollution levels caused by the numerous automobiles and 50 scheduled diesel trains, the concentration levels of other elements are so low that they have little or no effect on human life.

4.4 The enrichment factor of airborne elements

Airborne elements may be derived either from the natural sources, such as sea spray, surface soil, burning forests, and volcanic eruptions, etc., or from anthropogenic sources, such as soot from the combustion of automobiles and boilers, coal ash from power stations, incinerators and the minute waste materials from mechanical industrial processes, etc. In this study, in order to evaluate whether the airborne elements are derived from the anthropogenic sources, the values of the enrichment factor of the airborne elements are illustrated and the summary of the enrichment factor of the airborne elements at five land use areas is listed in Table 4.7.

The mean value of enrichment factor (EF) of the Mn at all monitoring sites, and those of the Cr, Ni at all monitoring sites except Kwai Chung District are below 1. However, even at the industrial area e.g. Kwai Chung District, the mean EF values of Cr and Ni are just slightly over 1. These values reflect the fact that these elements found in the ambient air mainly come from the natural sources in Hong Kong, and the emission of these elements from anthropogenic sources is not a serious problem.

Copper and zinc are common materials for building, engineering equipments, etc., and they act as alloys in many metal products. Thus, the weathering of the surface of these materials and the minute particles emitting from the metal products workshops or other related factories are the main anthropogenic sources of Cu and Zn in the ambient air. Because of the extensive consumption

Table 4.7 The enrichment factor of airborne elements at five land-use areas

Element \ Enrichment Factor \ Site		C.U.H.K.	Kwai Chung	Sham Shui Po	Tai Kok Tsui	Kowloon Tong
Cu	Min. Mean Max.	ND 2.43 10.4	1.99 6.87 55.04	1.14 3.85 12.31	0.71 3.61 12.95	0.76 2.50 12.70
Zn	Min. Mean Max.	ND 22.9 554.9	15.6 67.1 167.2	1.8 26.6 77.3	5.3 51.0 390.1	3.5 17.7 67.5
Ni	Min. Mean Max.	ND 0.828 9.632	ND 1.252 5.011	ND 0.659 2.019	ND 0.839 3.144	ND 0.585 1.649
Pb	Min. Mean Max.	15.6 377.515 1276.304	43.906 394.434 1918.826	57.9 160.9 330.0	80.1 205.0 592.2	35.0 168.9 361.3
Mn	Min. Mean Max.	0.082 0.232 0.575	0.107 0.279 0.519	0.159 0.311 0.526	0.141 0.357 1.267	0.136 0.252 0.578
Cd	Min. Mean Max.	ND 35.6 155.2	ND 23.7 60.7	ND 29.7 78.7	ND 28.7 129.0	ND 20.2 78.3
Cr	Min. Mean Max.	ND 0.204 0.683	0.181 1.565 20.853	ND 0.339 1.655	Not analysed	ND 0.124

ND: below detection limits

of these metals in modern cities, the mean EF values at all monitoring sites are greatly higher than 1, and they are especially high in the industrial areas e.g. Kwai Chung District and Tai Kok Tsui District, as there are multifarious factories contributing these pollutants.

The mean EF values of lead in the ambient air at all monitoring sites are so high as to be hundreds times the natural ratio of iron and lead in the earth's crust. At the monitoring sites of Kwai Chung District and Tai Kok Tsui District, as the samplers sited nearby the high traffic flow main road, the EF of Pb are typically higher. And, if the many anthropogenic sources of Fe did not exist, the EF of lead may be higher than what now it is.

At the campus of C.U.H.K. as the numerous automobiles are the main pollution sources, the EF of lead is relatively high.

The enrichment factor of Cd is high enough to be ten times. Nevertheless, the concentration of Cd is low at each monitoring site. As Cd is a trace element in the natural environment, the ratio between Fe and Cd in the crust is so low that only the small amount of Cd derived from the anthropogenic sources may greatly raise the value of enrichment factor. The possible anthropogenic sources of Cd at these monitoring sites may be the burning of refuse, emissions from electroplating factories, and combustion process of petrochemical energy (Kran Lan et al., 1971).

4.5 Discussion

At the monitoring site of Sham Shui Po District, poor ventilation conditions for the diffusion of the pollutants can be imagined as "street canyons" in which the narrow streets are barred by the closely erect multi-storey buildings, as shown in Figure 4.2, the pollutants may be accumulated in the canyons. Many reports claim that people living in such conditions for a long time may suffer from respiratory illness or other diseases. As the similar features of "street canyons" are commonly found in the most part of the commercial-residential areas in Hong Kong, it is believed that many citizens do day by day live in an unhealthy environment.

In this study, the Kwai Chung District is taken as representative of the industrial areas, which are dominated by the multi-storey industrial buildings with various types of factories. The particulate pollution level (with respect to either the mass concentration of TSP or the concentration of elements in ambient air) has caused a very serious situation to this area. The ambient air quality tested in most of the sampling days is far above the maximum permitted level set by various countries. It can be confired that long exposure to this pollution situation will be injurious to the health of the workers who have to stay for 8-10 hours in every working day in this district. Moreover, as the situation that the dense residential buildings are located just next to these industrial buildings is very common in Hong Kong, a city with dense population, the effect of such worst ambient air quality may be even more serious for the nearby dwellers.

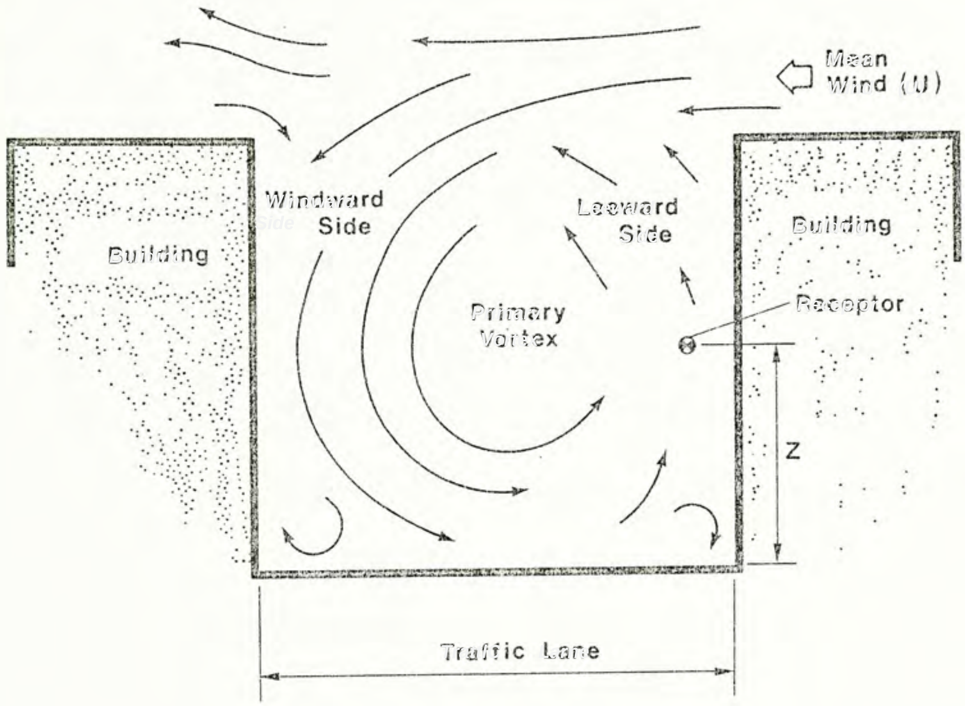

Figure 4.2 Schematic cross-section circulation between buildings.

(After Johnson et al, 1971)

Moreover, many roads of high traffic flow volume are enclosed by the nearby blocks of high buildings. In such "street canyons", both the Pb and soot pollution derived from the numerous automobiles would be very dangerous for the dwellers living at the ground or lower floors as they would be poisoned or suffer from inhaling large quantities of lead-laden air. As shown in Table 4.3 the Pb pollution is so serious that it is far above the maximum permitted level set by various countries. The extreme high EF of Pb is evidence that most lead contaminants come from the anthropogenic sources, e.g. automobiles.

According to the chemical properties of the elements, Zn, Pb and Cu are the volatile elements (Crecelius, 1980). They are easily enriched in the minute and proliferous particulates, and can be broadly dispersed in the atmosphere. Therefore, they all showed a high EF at all five monitoring sites. Of course, the great amount of related pollution sources close to the monitoring sites is also an important factor.

Table 4.8 and Figure 4.3 showed the concentration and enrichment factor of elements in airborne particles in some other countries. By comparing the particulate pollution level from each other, it is concluded that the pollution situation in Hong Kong cannot be considered as serious. The problems are similar to those of other industrialized and modernized cities, but an extremely high Pb concentration was detected in Hong Kong in comparison with the maximum values at other cities.

Table 4.8 The concentrations of airborne elements in various metropolitan areas

Cities \ Item		TSP	Heavy Metals							
			Fe	Cu	Zn	Ni	Pb	Mn	Cr	Cd
Tokyo	Mean	220	4.5	0.068	<1.1	0.05	<0.30	0.15	<0.04	
	Min.	74	0.6	0.015	<1.1	<0.03	<0.30	<0.10	<0.04	
	Max.	419	13.7	0.250	2.1	0.11	1.18	0.35	0.047	
New York	Mean		3.4	0.37	0.4	0.187	1.9	0.05	0.002	0.000
Birmingham	Mean	142	1.7	0.06	1.09	0.004		0.15	0.005	0.008
Peking	Mean	525	16.8	0.098	0.56	0.024	0.56	0.71	0.031	0.008
	Min.	130	0.97	0.02	0.02	0.004	0.13	0.07	0.007	0.0001
	Max.	1550	130.7	0.25	1.63	0.05	1.36	3.5	0.07	0.0016
Hong Kong	Mean	145.4	2.29	0.080	1.05	0.02	1.05	0.09	0.02	0.0018
	Min.	7.0	0.15	ND	ND	ND	0.03	0.01	ND	ND
	Max.	478.8	10.87	2.228	20.18	0.24	11.83	0.46	1.16	0.009

Units: $\mu g/m^3$

ND : below detection limits

Sources: (Wong, et al., 1980), (Corn, 1976), (Butler, 1979) and (Kran Lan et al., 1972).

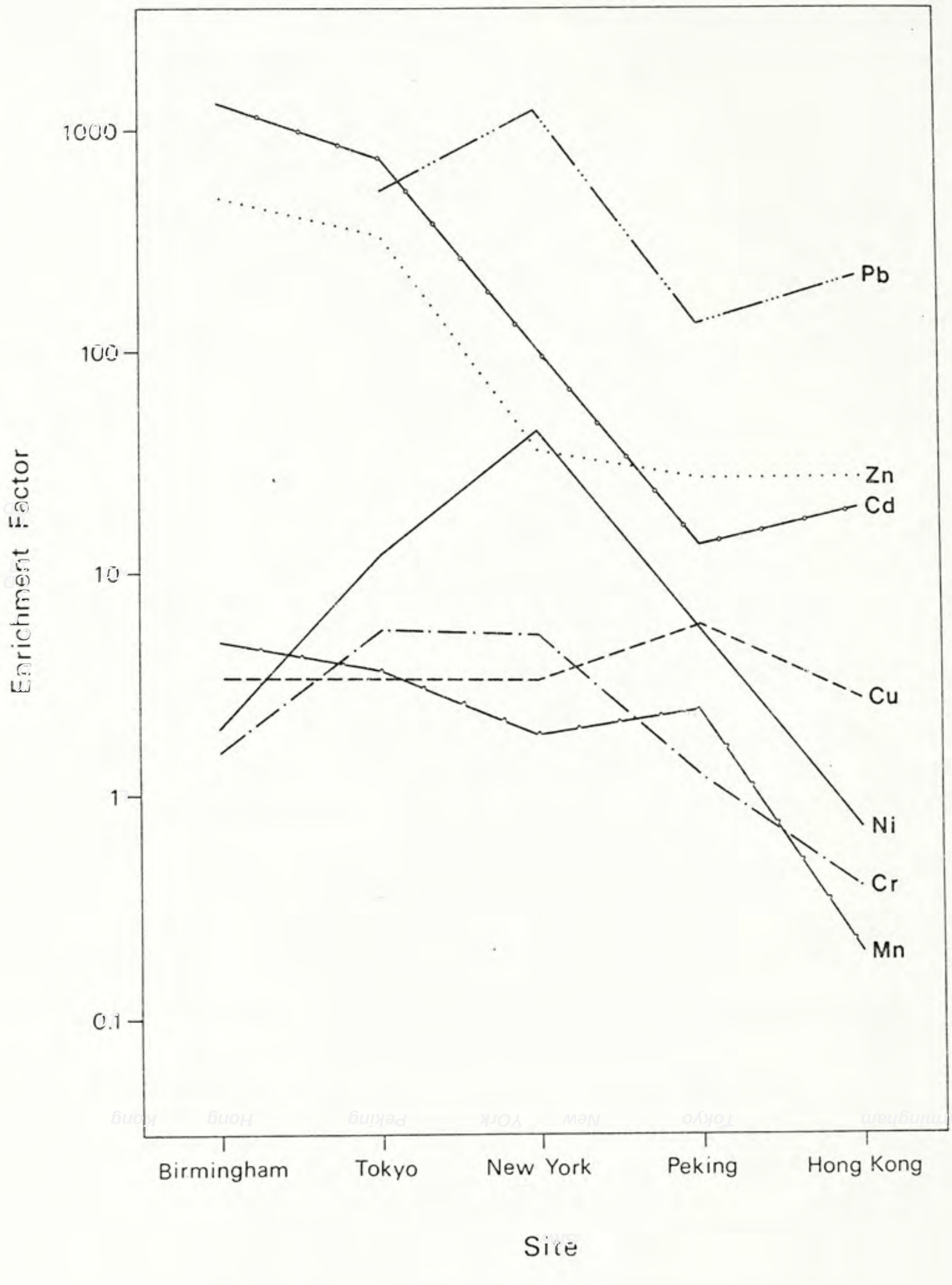

Figure 4.3 Enrichment factor of elements in airborne particles in some other countries.

Source: Wong, et al. (1980).

Moreover, the source of the Pb pollution in Hong Kong are similar to other advanced cities, the high EF of Pb gave the evidence that in these metropolitan areas, the Pb mainly comes from the anthropogenic sources, i.e. automobiles. The EF of Zn, Mn and Cd in Hong Kong are lower than the other cities, because there are no important heavy industrial mills which are the main sources of these elements.

The areal differences of the particulate pollution level (with respect to mass concentration) are quite real, thus the ambient air quality bill, which is to establish air standards for the Colony, ought to take into consideration the spatial variations in the particulate emissions levels. Divisional ambient air quality standards for different land use areas are practicable and unavoidable.

CHAPTER V

VERTICAL VARIATION OF PARTICULATE POLLUTION

5.1 Introduction

In a densely populated metropolitan area, it is believed that the "street canyon" effect and the eddies between the building blocks may cause the accumulation of pollutants at the lower-floors of the buildings; the high traffic flow volume also causes particulate pollution at the ground level. Moreover, in Hong Kong, soot and the smoke-exhausts emitted from the boilers of large restaurants are commonly found at the lower floors in the residential or commercial districts.

As many residential buildings are located just next to the industrial areas, the chimmeys on the roofs of those multi-storey industrial buildings may emit exhaust and disperse numerous pollutants and thus broadly affect the ambient air quality of the higher floors. Moreover, in many commercial and residential areas, there are a great number of various small-scale factories on the roofs and the higher floors of the buildings. The products produced by these factories are as follows: wearing, knitting, garment and fur products; plastics; watch case, toys and metal products; engraved wooden wares and furniture, etc.

As the pollution situation is quite complicated in Hong Kong, the common idea of the layman that those living in the higher floors may enjoy relatively fresh air may not necessarily be true. Therefore, in the study of particulate pollution in Hong Kong, it is necessary to understand the pollution status not only at the ground level, but also at the roof level, especially in the urban areas. The comparison of the pollution levels between the ground-level and the roof-level ambient air is also an interesting aspect of study.

5.2 Vertical variation at Sham Shui Po District

(a) The mass concentration

The mean of the mass concentration of the TSP at the ground-level is 276.7 $\mu g/m^3$, and the maximum value is 328.7 $\mu g/m^3$. Both are higher than the primary standards of ambient air quality set by the U.S. EPA. The mean of mass concentration of the TSP at the roof-level is 247.8 $\mu g/m^3$, and the maximum value is 280.9 $\mu g/m^3$, which is just slightly higher than this primary standard. The results show that the mass concentration of TSP in the ground-level ambient air seems to be more serious than that in the roof ambient air (see Table 5.1).

In order to determine whether the mass concentration of TSP at the ground-level is significantly higher than that at the roof-level, the paired T-test method is employed. It's result shows that the mass concentration of TSP at the ground-level is significantly higher than that at the roof-level (see Table 5.2). Otherwise, the correlation coefficient of these paired samples is

Table 5.1 The mass concentration of TSP at the roof and ground level ambient air at three land-use areas

Site \ Concentration		Mean	Max.	Min.
Sham Shui Po	Roof	247.8	280.6	201.7
	Ground	276.7	328.7	189.6
Kwai Chung	Roof	197.0	314.4	94.5
	Ground	318.4	409.6	240.3
Tai Kok Tsui	Roof	136.2	174.2	69.0
	Ground	143.7	232.8	84.2

Units: $\mu g/m^3$

Table 5.2 The paired T-test for comparison of the mass concentration of TSP between the roof and ground level ambient air at three land-use areas

Site		Mean $\mu g/m^3$	Difference* Mean	Standard ** Deviation	Simple Correlation	T Value	Degree of Freedom	2-Tail Prob.
Sham Shui Po	Roof Ground	247.8 276.7	-28.9	36.569	0.506	-2.50	9	0.034
Tai Kok Tsui	Roof Ground	136.2 143.7	-7.5	39.452	0.278	-0.68	12	0.505
Kwai Chung	Roof Ground	197.0 318.4	-121.3	64.316	0.332	-7.06	13	0.000

*: the mean of the difference between the paired observations

**: the standard deviation of the mean (difference)

0.506, which shows that a positive linear association of mass concentration of TSP between the ground-level and the roof-level does exist. This reflects that the particulate pollutants seem mainly to be derived from ground-based sources in this district.

These patterns of particulate pollution in Sham Shui Po District can be explained by the vertical land use pattern at this district. (Liang, 1972) indicated that the centralization of commercial land use at Mong Kok District has caused a continuously westward push effect on original residential land use into the nearby Sham Shui Po District. The small-scale industrial factories originally existed at the upper floors in Sham Shui Po District were consequently pushed westward into Cheung Sha Wan and Kwai Chung District. It is believed that this process has existed continually during the past ten years as attested by the fact that the population of Sham Shui Po District is the highest in Hong Kong according to the 1981 population census. Therefore, the Sham Shui Po District is dominated by the residential landuse and fewer industries are found on the roofs and the other floors of the buildings. The restaurants and cooked-food stalls which are regarded as the main sources of soot emissions, are broadly and densely distributed at the ground floor. Otherwise, the high traffic flow volume on Tai Po Road and Cheung Sha Wan Road which are not far from the monitoring site, introduce a large amount of soot and particulates in the ground-level ambient air.

(b) The chemical compositions

At the Sham Shui Po District, the concentrations of airborne elements at the roof-level seem to be similar to those at the ground-level (see Table 5.3). The concentration of Mn, Cr, and Cd are also lower than the various permitted levels. However, the concentration of Pb at the roof-level is still higher than the various maximum permitted levels. It is beieved that the status of the Pb pollution is serious even in the roof-level ambient air.

In order to determine whether the concentration of airborne elements at the roof-level and those at the ground-level are significantly different, the pair T-test method is employed. Table 5.4 shows the summary results.

The results show that the concentration of Pb at the roof-level is significantly less than that at the ground-level at the significance level of 0.1. Since the exhaust from the combustion process of the automobiles is the main source of Pb in the atmosphere in the urban areas, and the high traffic volume can be seen on the nearby main roads, the higher Pb concentration being monitored at the ground-level is not surprising.

However, the concentrations of other airborne elements are not significantly different between the ground-level and the roof-level. This shows that there are no significant pollution sources for these elements and the values just indicate the background levels of such elements in present ambient air in the district.

This idea seems to be strengthened by comparing the enrichment factor of airborne elements at the ground-level and the roof-level ambient air (see Table 5.5). The results of paired T-test show

Table 5.3 The concentration of airborne elements at the roof and ground level ambient air at Sham Shui Po District

Elements \ Concentration		Mean	Max.	Min.
Fe	Roof	2.87	5.40	1.7003
	Ground	2.55	4.03	1.6354
Cu	Roof	0.07	0.16	0.0403
	Ground	0.06	0.10	0.0352
Zn	Roof	0.62	1.40	0.0665
	Ground	0.81	1.42	0.2677
Ni	Roof	0.037	0.05	0.022
	Ground	0.033	0.064	0.0099
Pb	Roof	0.732	0.885	0.3700
	Ground	0.866	1.287	0.6677
Mn	Roof	0.140	0.356	0.0367
	Ground	0.121	0.205	0.0503
Cr	Roof	0.016	0.023	ND
	Ground	0.012	0.033	ND
Cd	Roof	0.0022	0.0046	ND
	Ground	0.0013	0.0040	ND

Units: $\mu g/m^3$

ND : below detection limits

Table 5.4 The paired T-test for comparison of the concentration of airborne elements between the roof and ground level at Sham Shui Po District

Elements		Mean $\mu g/m^3$	Difference* Mean	Standard ** Deviation	Simple Correlation	T Value	Degree of Freedom	2-Tail Prob.
Fe	Roof Ground	2.5525 2.8780	0.3254	1.147	0.270	0.90	9	0.393
Cu	Roof Ground	0.0604 0.0791	0.0188	0.043	-0.083	1.37	9	0.203
Zn	Roof Ground	0.8166 0.6203	-0.1962	0.678	-0.220	-0.92	9	0.384
Ni	Roof Ground	0.0334 0.0370	0.0036	0.025	-0.021	0.45	9	0.662
Mn	Roof Ground	0.8669 0.7328	-0.1341	0.198	0.314	-2.15	9	0.060
Pb	Roof Ground	0.1212 0.1408	0.0196	0.108	-0.021	0.57	9	0.581
Cr	Roof Ground	0.0125 0.0162	0.0037	0.013	-0.006	0.93	9	0.376
Cd	Roof Ground	0.0013 0.0022	0.0009	0.003	0.114	1.11	9	0.295

*: the mean of the differences between the paired observations

**: the standard deviation of the mean (difference)

Table 5.5 The paired T-test for comparing the enrichment factor of airborne elements between roof and ground level ambient air at Sham Shui Po

Element		Mean	Difference Mean	Standard Deviation	Corr.	T Value	Degree of Freedom	2-Tail Prob.
Cu	Roof	2.6562	0.7049	1.320	0.057	1.69	9	0.125
	Ground	3.3611						
Zn	Roof	30.6229	-10.2202	28.998	-0.419	-1.11	9	0.294
	Ground	20.4027						
Ni	Roof	1.0586	0.1367	0.636	0.048	0.68	9	0.514
	Ground	1.1953						
Pb	Roof	175.4734	-30.5598	60.553	0.215	-1.60	9	0.145
	Ground	144.9135						
Mn	Roof	0.3140	0.0079	0.242	-0.559	0.10	9	0.920
	Ground	0.3219						
Cr	Roof	0.2853	0.0914	0.314	-0.163	0.92	9	0.381
	Ground	0.3767						
Cd	Roof	24.1050	4.3384	29.028	0.053	0.47	9	0.648
	Ground	19.7666						

that enrichment factor of all airborne elements between both levels do not differ even at 0.1 significantly level. It is believed that the elemental nature of the ambient air between both levels is similar.

Moreover, the enrichment factor of Mn, Cr are lower than 1 at both levels which reflect that these elements are derived from natural sources. Otherwise, the enrichment factors of Pb at both levels are greatly higher than 1, which reflects the serious Pb pollution existing in the ambient air in this district (see Table 5.5).

5.3 Vertical variation at Tai Kok Tsui District

(a) The mass concentration

The mean and the maximum mass concentrations of TSP are 136.2 $\mu g/m^3$, 174.2 $\mu g/m^3$ at the roof-level, and 143.7 $\mu g/m^3$, 232.8 $\mu g/m^3$ at the ground-level respectively (see Table 5.1). The mean mass concentration at both levels seem to be not different and both are below the U.S. national primary standard. It is believed that the ambient air quality is not seriously harmful with respect to the mass concentration of TSP.

In order to determine whether the mass concentration of TSP at both levels are not different, the paired T-test method is employed. The result show that they are not significantly different at the 0.1 significance level and the correlation coefficient between two samples is 0.278, showing just a small positive association between them (see Table 5.2).

Liang (1972) indicated that the Tai Kok Tsui District is a industrial-residential land use area, in which small-scale factories are commonly found at the ground floor. As the pollution sources are distributed in vertical dimension, it is not surprising that the mass concentrations of TSP at the roof-level ambient air is similar to that at the ground-level ambient air.

(b) Chemical composition

At the Tai Kok Tsui District, it is interesting that with the exception of Pb, the concentrations of all airborne elements at roof-level are slightly or significantly higher than those at ground-level (see Table 5.6 and Table 5.7).

These results can be traced to the vertical land use pattern at this district. Liang (1972) indicated that in such mixed industrial and multi-storey residential zone, the vertical land uses except for the ground-floor are the combination of industrial and residential. The mixing ratio of industrial to residential use did gradually increase even to gain access to 100% at the top floor from the ground-floor upward. Even the roofs of the buildings are usually utilized as godowns or taken as the workshops for various types of products. In the past ten years, many constructions of new residential buildings have been in progress to replace such old Chinese-type multi-storey buildings within this district. For the field surveys, although the samplers were sited on a recently built residential building, those old mixed-use multi-storey buildings

Table 5.6 The concentration of airborne elements at the roof and ground level ambient air at Tai Kok Tsui District

Elements \ Concentration		Mean	Max.	Min.
Fe	Roof	2.32	3.53	1.17
	Ground	2.22	4.08	1.42
Cu	Roof	0.13	0.17	0.05
	Ground	0.06	0.12	0.01
Zn	Roof	1.98	10.31	0.205
	Ground	1.28	3.29	0.084
Ni	Roof	0.051	0.154	0.015
	Ground	0.019	0.036	ND
Pb	Roof	0.674	1.098	0.408
	Ground	0.784	1.292	0.487
Mn	Roof	0.152	0.295	0.040
	Ground	0.140	0.340	0.030
Cd	Roof	0.0021	0.0045	ND
	Ground	0.0015	0.0047	ND

Units: $\mu g/m^3$

ND : below detection limits

Table 5.7 The paired T-test for comparison of the concentration of airborne elements between the roof and ground level at Tai Kok Tsui District

Elements		Mean $\mu g/m^3$	Difference* Mean	Standard ** Deviation	Simple Correlation	T Value	Degree of Freedom	2-Tail Prob.
Fe	Roof Ground	2.3209 2.2268	0.0941	1.068	0.140	0.32	12	0.756
Cu	Roof Ground	0.1345 0.0604	0.0741	0.030	0.726	0.97	12	0.000
Zn	Roof Ground	1.9816 1.2871	0.6945	3.197	0.062	0.78	12	0.449
Ni	Roof Ground	0.0516 0.0194	0.0322	0.034	0.258	3.40	12	0.005
Pb	Roof Ground	0.6743 0.7840	0.1096	0.270	0.192	-1.47	12	0.169
Mn	Roof Ground	0.1524 0.1400	0.124	0.114	0.320	0.39	12	0.702
Cr	Roof Ground	0.0021 0.0015	0.0006	0.001	0.563	1.51	12	0.157

*: the mean of the difference between the paired observations

**: the standard deviation of the mean (difference)

are still broadly distributed nearby the monitoring sites. The pollutants emitting from such small-scale factories at the roof or upper floors cause a higher concentration of elements in the roof-level ambient air.

The concentration of Pb at the ground-level is slightly, but not significantly higher than that at the roof-level (see Table 5.7). Since the monitoring site at the ground is exposed to the strong sea breeze, the "street canyon" effect is not significant and the Pb concentration is diluted by the onshore prevailing wind.

Otherwise, the maximum and mean concentrations of Mn and Cd are lower than the various ambient air quality standards at both levels, but the maximum and mean concentrations of Pb are 1.0967, 0.6743 at the roof-level, and 1.2921, 0.7840 at the ground-level respectively (see Table 5.6). They are of very serious concern since both are higher than any national ambient air quality standards.

By comparing the enrichment factors of the airborne elements, the significantly higher enrichment factors of Cu and Ni are detected at the roof-level ambient air (see Table 5.8). These reflect the fact that there are more metal related factories, e.g. metal decoration, hardware, and small electronic factories distributed in the upper floors of the buildings in this district. For the other elements, the differences are not significant between the both levels, and these show that the pollutants do come from similar sources.

Table 5.8 The paired T-test for comparing the enrichment factor of airborne elements between roof and ground level ambient air at Tai Kok Tsui

Element		Mean	Difference Mean	Standard Deviation	Corr.	T Value	Degree of Freedom	2-Tail Prob.
Cu	Roof Ground	7.4600 3.0787	4.3813	3.320	0.482	4.76	12	0.000
Zn	Roof Ground	77.5314 79.6116	-502.0801	1866.341	0.715	-0.97	12	0.351
Ni	Roof Ground	2.2174 0.7762	1.4412	1.474	0.290	3.53	12	0.004
Pb	Roof Ground	153.0030 183.1807	-30.1777	78.225	0.062	-1.39	12	0.189
Mn	Roof Ground	0.3887 0.3685	0.0202	0.147	0.524	0.50	12	0.629
Cd	Roof Ground	31.6516 19.2750	12.3766	27.518	0.087	1.62	12	0.131

5.4 Vertical variation at Kwai Chung District

(a) The mass concentration

The mean mass concentration of TSP is 197.0 $\mu g/m^3$ at the roof-level, and 318.4 $\mu g/m^3$ at the ground-level. The latter is far above the various national ambient air quality standard. Otherwise, the maximum level is 314.4 $\mu g/m^3$ at the roof and 409.6 $\mu g/m^3$ at the ground-level (see Table 5.1). These results reflect that the particulate pollution at the ground-level ambient air is much worse.

However, the paired T-test is employed again to test whether the difference do exist between the mass concentrations of TSP at both levels. The observed significance level is 0.000 (see Table 5.2), which indicates that the mass concentration of TSP at the ground-level is very significantly higher than that at the roof-level. Otherwise, the correlation coefficient of these paired samples is 0.332, which shows that a weak positive linear association between mass concentrations of TSP between both levels does exist. This significant difference may be explained by observation of the existing pollution sources and ventilation conditions in this district.

From the field survey within 50 m distance from the monitoring site, it is found that only 3 chimneys were counted, and that most of the waste gases and minute solids are directly exhausted through the windows by the exhaust system. Therefore, pedestrians in this district can feel that the air is full of dust and smells unpleasant during the working hours. The numerous heavy lorries passing by leave much dark soot which may also raise the concentration of particulates in ground-level ambient air.

Otherwise, since this district was newly developed since 1970, the industrial buildings are typically high (The building that the sampler site on is 33 storeys). To compare this great height with the width of the narrow streets, the "street canyon effect" can be imagined and this effect may lead to the poor ventilation conditions at the ground-level ambient air. On the converse, as the building is high enough, the better ventilation conditions cause a greater dispersion of suspended particulates in roof-level ambient air. This is why the mass concentration of TSP at the roof-level is less than that at the ground-level.

(b) Chemical compositions

Except for Cu, the concentrations of other airborne elements at the roof-level are lower than those at the ground-level (see Table 5.9). Conversely, the concentration of Cu at the roof-level is higher than that at the ground-level. In order to determine the difference that do exist between both levels, a paired T-test is employed. The results show that the concentration of Cu at the roof-level is significantly higher than that at the ground-level and for other elements except Cd and Ni, concentrations at the roof-level are significantly lower than those at ground-level (see Table 5.10).

Among these elements, only the concentration of Pb at both levels, and some extreme concentrations of Cr at the ground-level are higher than the various national ambient air quality standards, the concentration of other elements are not of serious concern.

Table 5.9 The concentration of airborne elements at the roof and ground level ambient air at Kwai Chung District

Elements \ Concentration		Mean	Max.	Min.
Fe	Roof	2.32	5.0	1.0
	Ground	5.04	10.0	1.7
Cu	Roof	0.47	0.8	0.25
	Ground	0.24	0.5	0.07
Zn	Roof	1.05	1.83	0.52
	Ground	4.32	17.13	0.39
Ni	Roof	0.128	0.42	0.05
	Ground	0.099	0.23	0.04
Pb	Roof	1.02	1.52	0.41
	Ground	3.80	11.83	1.74
Mn	Roof	0.096	0.205	0.036
	Ground	0.202	0.441	0.061
Cr	Roof	0.031	0.050	0.010
	Ground	0.090	0.241	0.006
Cd	Roof	0.0026	0.006	ND
	Ground	0.0024	0.007	ND

Units: $\mu g/m^3$

ND : below detection limits

Table 5.10 The paired T-test for comparison of the concentration of airborne elements between the roof and ground level at Kwai Chung District

Elements		Mean $\mu g/m^3$	Difference* Mean	Standard ** Deviation	Simple Correlation	T Value	Degree of Freedom	2-Tail Prob.
Fe	Roof	2.3210	-2.7266	2.707	0.145	-3.77	13	0.002
	Ground	5.0476						
Cu	Roof	0.4749	0.2304	0.242	-0.235	3.57	13	0.003
	Ground	0.2446						
Zn	Roof	1.0529	-3.2726	4.539	-0.075	-2.70	13	0.018
	Ground	4.3256						
Ni	Roof	0.1289	0.0297	0.127	-0.219	0.88	13	0.397
	Ground	0.0992						
Pb	Roof	1.0206	-2.7827	3.261	0.130	-3.19	13	0.007
	Ground	3.8033						
Mn	Roof	0.0965	-0.1061	0.121	0.028	-3.27	13	0.006
	Ground	0.2026						
Cr	Roof	0.0317	-0.0585	0.069	0.130	-3.15	13	0.008
	Ground	0.0902						
Cd	Roof	0.0026	0.0002	0.002	0.340	0.37	13	0.720
	Ground	0.0024						

*: the mean of the differences between the paired observations

**: the standard deviation of the mean (difference)

Poor ventilation conditions at the ground-level may lead to a higher concentration of such elements, but the electronic and electrical factories mainly distributed in the upper floors may be possible sources for the higher concentrations of Cu in roof-level ambient air. As numerous heavy lorries pass by within this district, their exhaust fumes may release much airborne Pb into the air. A hgih Pb concentration can be detected in the ambient air both at the ground-level and the roof-level. In an extreme case, the concentration of Pb at the ground-level is 11.8 $\mu g/m^3$, which is far above the various national ambient air quality standards and would serious affect the public health of the residents living nearby.

Except Mn, the enrichment factor of other airborne elements is either much or slightly more than 1, (see Table 5.12), which indicates that airborne elements in the ambient air do partly or mainly derive from anthropogenic sources. The higher EF of copper in roof-level ambient air shows that there may be more related anthropogenic sources in the upper floors. The small value of the enrichment factor of Mn refects that it may be mainly derived from natural sources even in this industrial area.

5.5 Discussions

The vertical variation of the particulate pollution in the scale of a high building is multifarious. The actual case depends on vertical land use patterns, ventilation conditions in the lower floors, and the surrounding environment as well as remote pollution

Table 5.11 The paired T-test for comparing the enrichment factor of airborne elements between roof and ground level ambient air at Kwai Chung

Element		Mean	Difference Mean	Standard Deviation	Corr.	T Value	Degree of Freedom	2-Tail Prob.
Cu	Roof Ground	25.2637 5.6522	19.6115	8.099	0.557	9.06	13	0.000
Zn	Roof Ground	38.1542 63.9575	-25.8033	47.311	-0.473	-2.04	13	0.062
Ni	Roof Ground	4.9864 1.8743	3.1121	3.355	-0.080	3.47	13	0.004
Pb	Roof Ground	235.2431 512.1782	-276.9351	566.506	0.402	-1.83	13	0.090
Mn	Roof Ground	0.2726 0.2674	0.0051	0.083	0.268	0.23	13	0.820
Cr	Roof Ground	1.0631 1.2045	-0.1414	0.934	0.285	-0.57	13	0.581
Cd	Roof Ground	41.2006 22.5858	18.6147	25.543	-0.147	2.73	13	0.017

Table 5.12 The enrichment factor of airborne elements at the roof and ground level ambient air at three land-use areas

			Ni	Pb	Mn	Cr	Cd	Cu	Zn
Kwai Chung	Roof	Max.	12.8	380.2	0.48	2.27	66.4	48.5	54.5
		Mean	4.9	235.2	0.27	1.06	41.2	25.2	38.1
		Min.	1.6	138.8	0.19	0.56	ND	13.8	0.5
	Ground	Max.	5.0	1918.8	0.36	3.36	60.7	7.9	154.0
		Mean	1.8	512.1	0.26	1.20	22.5	5.6	63.9
		Min.	0.4	155.4	0.19	0.24	4.3	1.9	17.1
Sham Shui Po	Roof	Max.	2.0	229.5	0.58	0.72	73.5	5.7	41.1
		Mean	1.1	144.9	0.32	0.37	24.1	3.3	20.4
		Min.	0.1	34.2	0.12	ND	ND	1.3	3.0
	Ground	Max.	1.6	287.0	0.48	0.55	47.0	3.8	77.3
		Mean	1.0	175.4	0.31	0.28	19.7	2.6	30.6
		Min.	0.4	130.8	0.20	ND	ND	2.21	11.4
Tai Kok Tsui	Roof	Max.	4.7	269.3	0.59	NA	91.6	15.9	98.1
		Mean	2.2	153.0	0.38	NA	31.6	7.4	39.0
		Min.	0.5	83.0	0.18	NA	ND	2.4	7.4
	Ground	Max.	1.5	315.0	0.56	NA	65.5	5.6	141.8
		Mean	0.7	183.1	0.36	NA	19.2	3.0	41.1
		Min.	ND	103.9	0.14	NA	ND	0.7	5.3

ND: below detection limits

NA: not analyzed

sources. Thus, the ambient air quality at the roof-level may not be necessarily be better than that at the ground-level.

Where many tall multi-storey buildings are congested together, the serious "street canyon" effect may cause a worser particulate pollution level at the lower floors. In these areas, to live at the upper floors may be the better choice.

As the mean Pb concentrations are also detected to exceed various maximum permitted levels at three roof-monitoring sites, it is believed that people living in the urban areas are usually suffering from pollution and may be chronically poisoned even when they are living in the upper floors.

The samplers for monitoring roof-level ambient air are not situated at the same height (the monitoring site at Sham Shui Po District is at the roof of 12 storeys, at Tai Kok Tsui is 22 storeys, and at Kwai Chung is 33 storeys). Because of this fact, it is not necessary to compare them. As shown in the data, the mass concentration of TSP at the roof-level is 197 $\mu g/m^3$ at Kwai Chung and 247.8 $\mu g/m^3$ at Sham Shui Po, and it is believed that the taller the buildings, the greater may be the variation, but this assumption cannot be evaluated here due to limited and unrepresentative observations.

As vertical variations in particulate pollution levels really do exist, the observed air quality monitored at the roof of the building may not be exactly the ambient air quality of the represented region. Therefore, for monitoring and managing the particulate pollution problem, which site is most appropriate to be adopted for the study of ambient air quality is an important issue especially in a city full of dense and tall buildings within which the "street canyon" effect is serious.

CHAPTER VI

THE IMPLICATIONS OF METEOROLOGICAL PARAMETERS IN THE PARTICULATE POLLUTION

6.1 Introduction

The implications of many meteorological parameters in the particulate pollution have been assessed by numerous authors. However, this study only tries to reveal the relationship between the particulate pollution level and the mixing depth, rainfall, and wind speed. The effect of the strong wind on the dispersion of airborne particulate in the urban areas is also evaluated by two-sample T-test. Moreover, the implications of such meteorological parameters in the particulate pollution are quite complicated and strongly influenced by local conditions, source-receptor relationship and micrometeorological conditions. The practical situations are discussed below in detail.

6.2 Regression analysis

In this section, the daily maximum mixing depth, the daily amount of rainfall and the daily average wind speed in each sampling day are taken into account in evaluating their relationships to the particulate pollution levels at each monitoring site through multiple regression procedures. Following the use of a computer, the standardized regression equations for the monitoring sites are listed below:

$$Y_M = -0.145X_1 - 0.072X_2 - 0.164X_3 \text{ (Kwai Chung) } \ldots\ldots 1$$

$$Y_M = -0.109X_1 + 0.408X_2 - 0.170X_3 \text{ (Sham Shui Po) } \ldots\ldots 2$$

$$Y_M = -0.181X_1 - 0.045X_2 + 0.193X_3 \text{ (Tai Kok Tsui) } \ldots\ldots 3$$

$$Y_M = -0.052X_1 + 0.352X_2 + 0.291X_3 \text{ (Kowloon Tong) } \ldots\ldots 4$$

$$Y_M = -0.221X_1 + 0.195X_2 + 0.200X_3 \text{ (C.U.H.K.) } \ldots\ldots 5$$

where X_1 = the amount of daily rainfall

X_2 = the daily average wind speed

X_3 = the daily maximum mixing depth

Y_M = the mass concentration of TSP in the ambient air

However, in the regression analysis, some procedures ought to be employed to determine whether the variability of the pollution level is implicated in the predictors (independent variables) or only in other uncertain factors, or sampling fluctuation due to measurement error. These testing procedures include: (1) the overall F-test; (2) the F-test for a subset of regression coefficients; (3) the F-test for a specific regression coefficient (refer to 3.5).

The overall F-test is employed to determine whether or not the variation in pollution levels is significantly explained by the combined linear influence of independent variables (see Table 6.1). The results indicate that at the four monitoring sites in the urban area, the observed significance levels are greater than 0.05, which means that the multiple R of these variables is equal to zero and the null hypothesis is accepted. At the site of C.U.H.K., the

Table 6.1 The overall F-test for goodness of fit of regression coefficients (dependent variable: mass concentration of TSP)

Site	Multiple R	R square	D.F. (K-1, N-K-1)	F Value	Sign. Level
Kwai Chung	0.207	0.043	(3, 32)	0.476	>0.1
Sham Shui Po	0.431	0.186	(3, 33)	2.51	<0.1
Tai Kok Tsui	0.337	0.117	(3, 34)	1.45	>0.1
Kowloon Tong	0.472	0.223	(3, 26)	2.488	<0.1
C.U.H.K.	0.392	0.153	(3, 88)	5.310	<0.05

Multiple R = multiple correlation coefficient

R square = square of multiple correlation

D.F. = degree of freedom

observed significance level of multiple R is less than 0.05, the null hypothesis is rejected and the combined influence of these variables can significantly explain the variation of pollution level. At the significance level of 0.1, the low significance of the muitiple R of the equation for Sham Shui Po District and Kowloon Tong District are detected.

These low or nil significances for the multiple R of the regression equations show that these three meteorological parameters together may not or may only partially explain the particulate pollution level in the urban areas. In contrast, in the open country (such as the campus of C.U.H.K.), these meteorological variables combined can significantly predict the particulate pollution level.

Since the insignificance of multiple R may be due to some extreme insignificant regression coefficients, a stepwise selection procedure is employed to determine which variables should be deleted from the equation (refer to 3.5). Below are the revised regression equations after the stepwise selection procedures (see Table 6.2).

Y_M = no variables (Kwai Chung) .... (1)'

$Y_M = -0.109X_1 + 0.408X_2 - 0.171X_3$ (Sham Shui Po) .... (2)'

$Y_M = 0.193X_3$ (Tai Kok Tsui) .... (3)'

$Y_M = -0.052X_1 + 0.352X_2 + 0.291X_3$ (Kowloon Tong) .... (4)'

$Y_M = -0.221X_1 + 0.195X_2 + 0.200X_3$ (C.U.H.K.) .... (5)'

Table 6.2 The F-test for a subset of regression coefficient of variables in the equation (dependent variable: mass concentration of TSP)

Site	Variables in the equation	Multiple R	R square	D.F. (K-1, N-K-1)	F Value	Sign level	Increment* of R	Increment* of R^2
Kwai Chung	Mixing depth	0.122	0.015	(1, 34)	0.514	>0.1	0.085	0.028
Sham Shui Po	Wind speed Mixing depth Rainfall	0.431	0.186	(3, 33)	2.510	<0.1		
Tai Kok Tsui	Mixing depth	0.292	0.085	(1, 36)	3.344	<0.1	0.045	0.032
Kowloon Tong	Wind speed Mixing depth Rainfall	0.472	0.223	(3, 26)	2.488	<0.1		
C.U.H.K.	Rainfall Wind speed Mixing depth	0.392	0.153	(3, 88)	5.310	<0.05		

Multiple R = multiple correlation coefficient

R square = square of multiple correlation coefficient

D.F. = degree of freedom

* = derived from the insignificant variables, which are "variables not in the equation"

It is interesting that no variables can be entered into the equation for the monitoring site of Kwai Chung District at the 0.1 significance level. It reflects that not only all of the independent variables are combined, but also the most important variable is insignificant to predict the pollution level in such a polluted industrial area. Certainly, there should be some other uncertain factors contributing much effects on the particulate pollution rather than solely meteorological parameters.

However, even the subset of variables is significant and the multiple R of the subset of regression coefficient is assumed to be not zero, it does not mean that all regression coefficients are not zero since an extreme significant variable may greatly increase the significance of the subset of the variables. In order to determine which specific variable is significant. the F-test for the specific regression coefficient is employed in this study (refer to 3.5). The results is listed on Table 6.3.

Besides the mass concentration of TSP, the airborne Pb is the main anthropogenic pollutant in Hong Kong (refer to 4.2 and 4.3). Therefore, the implications of the meteorological parameters on this element are also drawn out through the same statistic procedures. The regression equations are listed below.

Table 6.3 The F-test for the specific regression coefficient

(dependent variable: concentration of TSP)

Site	Variable	B	Beta	STD error B	D.F. (1, N-K-1)	F value	Sign. level
Kwai Chung	Mixing depth	-0.39	-0.164	0.043	(1, 32)	0.833	>0.1
	Rainfall	-0.20	-0.145	0.250		0.636	>0.1
	Wind speed	-2.60	-0.072	0.275		0.171	>0.1
	(constant)	338.14					
Sham Shui Po	Wind speed	8.755	0.408	3.563	(1, 33)	6.038	<0.05
	Mixing depth	-0.340	-0.171	0.033		1.045	>0.1
	Rainfall	-0.427	-0.109	0.686		0.387	>0.1
	(constant)	207.20					
Tai Kok Tsui	Mixing depth	-0.196	0.193	0.019	(1, 34)	1.066	>0.1
	Rainfall	-0.317	-0.181	0.326		0.945	>0.1
	Wind speed	-0.520	-0.045	1.937		0.072	>0.1
	(constant)	148.71					
Kowloon Tong	Wind speed	5.777	0.352	2.895	(1, 26)	3.982	<0.1
	Mixing depth	0.420	0.291	0.026		2.598	>0.1
	Rainfall	-0.252	-0.052	0.885		0.081	>0.1
	(constant)	20.427					
C.U.H.K.	Rainfall	-2.58	-0.221	0.12	(1, 88)	4.395	<0.05
	Wind speed	2.22	0.195	1.12		3.919	<0.1
	Mixing depth	0.17	0.200	0.01		3.605	<0.1
	(constant)	38.79					

B = partial regression coefficient

Beta = standardized partial regression coefficient

(1) The initial model

$Y_P = -0.151X_1 - 0.139X_2 - 0.346X_3$ (Kwai Chung) ...... (1)

$Y_P = {}^*X_1 - 0.122X_2 - 0.274X_3$ (Sham Shui Po) .... (2)

$Y_P = -0.038X_1 - 0.429X_2 - 0.165X_3$ (Tai Kok Tsui) .... (3)

$Y_P = 0.128X_1 - 0.246X_2 - 0.194X_3$ (Kowloon Tong) ..... (4)

$Y_P = -0.084X_1 - 0.386X_2 - 0.058X_3$ (C.U.H.K.) .... (5)

(2) The revised model

$Y_P = -0.346X_3$ (Kwai Chung) .... (1)'

Y_P = no variables (Sham Shui Po) .... (2)'

$Y_P = -0.429X_2 - 0.165X_3$ (Tai Kok Tsui) .... (3)'

Y_P = no variables (Kowloon Tong) .... (4)'

$Y_P = -0.084X_1 - 0.386X_2 - 0.058X_3$ (C.U.H.K.) .... (5)'

where Y_P = the concentration of airborne Pb in the ambient air

After the overall F-test (see Table 6.4), it is also found that only at the campus of C.U.H.K. is the model significantly at the 0.05 significance level. It reflects that these meteorological parameters combined are insignificant for predicting the concentration of Pb at these districts in the urban area.

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*: The variable is too significant that the F-level and the tolerance levels are not sufficient for further calculation.

Table 6.4 The overall F-test for goodness of fit of regression coefficient (dependent variable: concentration) of Pb)

Site	Multiple R	R square	D.F. (K-1, N-K-1)	F Value	Sign. Level
Kwai Chung	0.369	0.136	(3, 32)	1.687	>0.1
Sham Shui Po	0.284	0.080	(3, 33)	1.492	>0.1
Tai Kok Tsui	0.425	0.181	(3, 34)	2.504	<0.1
Kowloon Tong	0.342	0.117	(3, 26)	1.150	>0.1
C.U.H.K.	0.407	0.165	(3, 82)	5.413	<0.05

Multiple R = multiple correlation coefficient

R square = square of multiple correlation coefficient

D.F. = degree of freedom

After the stepwise selection procedure (see Table 6.5), there are no variables entering into the equation for Sham Shui Po and Kowloon Tong Districts. This shows that the meteorological parameters have not significant influenced the variation of airborne Pb in these districts.

However, only the general properties of these regression model are introduced in this section, the relations of each meteorological parameters to the particulate pollution may be discussed in the following sections.

6.3 The precipitation

In the study, it is found that there are inverse relationships between the mass concentration of TSP and the daily rainfall at all monitoring sites. However, at the four monitoring sites in urban area, the amount of the daily rainfall are not significantly but just slightly explains the variation of the concentration of TSP, as the observed significance levels of the standardized regression coefficients are greater than 0.1 (see Table 6.7). For the airnorne Pb, an insignificant inverse relationship is found for all monitoring sites except the Kowloon Tong District. At the Kowloon Tong District, the relationship is even insignificantly positive. It is believed that in the urban area, the day-to-day fluctuations of the various small, low pollution sources and the complicated micrometeorological conditions due to the effect of congested high buildings may lead to more changes of particulate pollution level than the precipitation.

Table 6.5 The F-test for a subset of regression coefficient of variables in the equation (dependent variable: concentration of Pb)

Site	Variables in the equation	Multiple R	R square	D.F. (k-1, N-K-1)	F Value	Sign level	Increment* of F	Increment* of R^2
Kwai Chung	Mixing depth	0.300	0.090	(1, 34)	3.365	<0.1	0.069	0.046
Sham Shui Po	Mixing depth	0.257	0.066	(1, 35)	2.476	>0.1	0.027	0.014
Tai Kok Tsui	Wind speed Mixing depth	0.424	0.179	(2, 35)	3.839	<0.05	0.001	0.002
Kowloon Tong	Mixing depth	0.241	0.057	(1, 28)	1.722	>0.1	0.101	0.060
C.U.H.K.	Wind speed Rainfall Mixing depth	0.407	0.165	(3, 82)	5.413	<0.05		

Multiple R = multiple correlation coefficient

R square = square of multiple correlation coefficient

D.F. = degree of freedom

* = derived from the insignificant variables, which are "variables not in the equation"

Table 6.6 The F-test for the specific regression coefficient

(dependent variable: concentration of airborne Pb)

Site	Variable	B	Beta	STD error B	D.F. (1, N-K-1)	F value	Sign. level
Kwai Chung	Mixing depth	-0.050	-0.246	0.002	(1, 32)	4.099	<0.1
	Rainfall	-0.126	-0.151	0.014		0.761	>0.1
	Wind speed	-0.302	-0.139	0.361		0.699	>0.1
	(constant)	11.215					
Sham Shui Po	Mixing depth	-0.00308	-0.274	0.0002	(1, 33)	2.722	>0.1
	Wind speed	-0.149	-0.122	0.020		0.541	>0.1
	Rainfall*						
	(constant)	1.228					
Tai Kok Tsui	Wind speed	-0.384	-0.428	0.014	(1, 34)	7.161	<0.05
	Mixing depth	-0.0013	-0.165	0.0001		0.846	>0.1
	Rainfall	-0.0051	-0.037	0.0024		0.046	>0.1
	(constant)						
Kowloon Tong	Mixing depth	-0.00197	-0.194	0.0002	(1, 26)	1.018	>0.1
	Wind speed	-0.272	-0.236	0.022		1.571	>0.1
	Rainfall	-0.0435	0.128	0.006		0.429	>0.1
	(constant)	1.038					
C.U.H.K.	Wind speed	-0.590	-0.386	0.015	(1, 88)	14.565	<0.01
	Rainfall	-0.0175	-0.084	0.002		0.633	>0.1
	Mixing depth	0.00069	0.058	0.000		0.295	>0.1
	(constant)	0.967					

B = partial regression coefficient   Beta = standardized partial regression coefficient

* = the variable is too significant that the F-level or tolerance-level insufficient for further computation

Table 6.7 The relationship between the precipitation and the particulate pollution level

Site	TSP			Pb		
	B	Beta	Sign. Level	B	Beta	Sign. Level
C.U.H.K.	-2.58	-0.221	<0.05	-0.0175	-0.084	>0.1
Kowloon Tong	-0.252	-0.052	>0.1	-0.0435	0.128	>0.1
Tai Kok Tsui	-0.317	-0.181	>0.1	-0.0051	0.038	>0.1
Sham Shui Po	-0.427	-0.108	>0.1	*	*	*
Kwai Chung	-0.20	-0.164	>0.1	-0.126	-0.151	>0.1

TSP = mass concentration of total suspended particulates

B = partial regression coefficient

Beta = standardized partial regression coefficient

* = the variable is too significant that the F-level or tolerance-level are insufficient for further computation

In the open country as on the campus of C.U.H.K., the amount of precipitation can significantly predict the variation of the particulate pollution in the atmosphere since the observed significance level is less than 0.05. For instance, the minimum levels were recorded at two consecutive sampling days (29 December, 1982 and 30 December, 1982); the levels are 7.0 and 8.8 $\mu g/m^3$ respectively; the rainfall of those days are 71.1 mm and 20 mm per day respectively. This is an evidence that a lower particulate pollution level may be induced by the cleansing effect of the heavy rainfall.

With respect to the low ability of from precipitation to predict particulate pollution level, a defect in the regression models ought to be evaluated here. It is assumed that the cleansing effect of the precipitation would reduce the particulate pollution level not only on that rainy day but also on the succeeding days although it has no rainfall record. In these quantitative models, the precipitation effects on such succeeding days cannot be evaluated.

6.4 The wind speed

Many dispersion models dealing with a highly elevated emission source in the open country or the multiple, small, low volume sources in the urban area, take surface wind speed as a dispersion parameter. However, it is found that there are significant positive correlations between the monitoring sites at Sham Shui Po, Kowloon Tong and C.U.H.K., and insignificant inverse correlations for the monitoring sites at Tai Kok Tsui and Kwai Chung, between the mass concentration of TSP and the daily average wind speed (see Table 6.8). This is quite different from many models expected, but it is not surprising, since the effects of wind speed on the particulate pollution is reported to be quite complicated in the urban area by many studies (refer to 2.6).

At the Kowloon Tong District and the campus of C.U.H.K., the density of the population and buildings are low, and except the exhaust soot from the automobiles, there are no significant pollution sources. Therefore, there are less pollutants needed to be dispersed by the wind, and by contrast, the strong wind may lead to the resuspension of street dust and the surface soil. The significant positive relationship (see Table 6.8) between the TSP and the wind speed can be the evidence that the resuspension effect of the wind is implicated in the higher concentration of TSP in the ground-level ambient air. However, for the airborne Pb, a significant inverse relationship between wind speed and Pb concentration is the evidence that the strong wind is implicated in the lower concentration of airborne Pb in the ground-level ambient air on the campus of C.U.H.K. In the Kowloon Tong District, the dispersion effect of the wind on the airborne Pb is not significant since the correlation between the wind speed and the concentration of Pb is insignificant.

In the urban areas in Hong Kong, the buildings are typically high and congested. The roads are the "canyon-like" streets as they are relatively narrower to compare with the buildings. In sucy areas, the prevailing strong winds may cause a downwash effect

Table 6.8 The relationship between the wind speed and the particulate pollution level

Site	TSP			Pb		
	B	Beta	Sign.* Level	B	Beta	Sign.* Level
C.U.H.K.	2.22	0.194	<0.1	-0.590	-0.386	<0.01
Kowloon Tong	5.777	0.352	<0.1	-0.272	-0.236	>0.1
Tai Kok Tsui	-0.520	-0.044	>0.1	-6.384	-0.429	<0.05
Sham Shui Po	8.755	0.408	<0.05	-0.149	-0.122	>0.1
Kwai Chung	-2.60	-0.072	>0.1	-0.302	-0.139	>0.1

TSP = mass concentration of total suspended particulates

B = partial regression coefficient

Beta = standardized partial regression coefficient

* = the significance level of the Beta is determined by F-test (refer to Table 6.3 and 6.6)

behind the buildings and the eddies circulated within the street canyons, and both can accumulate the pollutants and raise the street dust in the "canyons" (see Figure 4.2). Thus, the measured ground-level TSP is strongly influenced by the aerodynamics of nearby high buildings and the dispersion effect of the wind is reduced. Therefore, at the Sham Shui Po District, as the monitoring site is surrounded by tall multi-storey buildings, the strong wind even causes a higher concentration of particulates, thus, the significantly positive correlation between the TSP and the wind speed is obtained (see Table 6.9). In contrast, an insignificant inverse relationship is found for the airborne Pb, it reflects the downwash effect for such emitting pollutants is not significant.

In the Tai Kok Tsui and Kwai Chung districts, the relationships between wind speed and the TSP are insignificantly inverse. It reflects that the dispersion effect of the wind is insignificant in the ground-level ambient air. However, in considering the airborne Pb, a significantly inverse relationship is found at the Tai Kok Tsui District, (see Table 6.10). These reflect that the strong wind still can disperse the emitted anthropogenic pollutants and reduce their concentration.

The results seem to show that in these districts, the wind may in some cases, resuspended the surface dust to raise the concentration of TSP, and in other cases, disperse the emitting pollutants to reduce the concentrations of such airborne elements. However, since the number of sampling days are small, the real effect of the wind speed cannot be assessed in this study. It needs much observations and further studies.

In order to determine the effect of calm wind conditions on build-up of pollutants in urban area, the two sample T-test is employed (refer to 3.5). At the monitoring sites of Kwai Chung and Tai Kok Tsui districts, there is not a significant difference between the two group means as the observed significance levels are 0.627 and 0.309 respectively (see Table 6.9). The results indicate that the build-up of the TSP in such districts may not be stagnate under the calm wind conditions (wind speed <6 knots/hr.).

At the monitoring site of Sham Shui Po, the mean concentration of TSP of group 1 is significant greater than that of group 2 at the 0.05 significance level. The results indicate that strong wind conditions may be likely to cause the concentration of pollution rather than the calm wind conditions in this district.

For the airborne Pb, at the monitoring sites of Kwai Chung and Sham Shui Po districts, there is not a significant difference between the two group means as the observed significance levels are 0.223 and 0.224 respectively (see Table 6.10). The results show that the calm wind conditions may not lead to the accumulation of the airborne Pb in the ground-level ambient air

At the Tai Kok Tsui District, the mean concentration of Pb in group 1 (wind speed greater or equal to 6 knots/hr.) is significantly less than that in group 2 (wind speed less than 6 knots/hr.) at the 0.05 significance level. The result indicates that the calm wind conditions may stagnate the airborne Pb in the ground-level ambient air.

Table 6.9 The T-test for the effects of wind speed on build-up TSP in the urban area

Site	Group	Number of Cases	Mean	Standard Deviation	Standard Error	T Value	Degree of Freedom	2-Tail Prob.
Tai Kok Tsui	Group 1 Group 2	20 18	166.3999 160.4221	41.027 34.150	9.174 8.049	0.49	35.80	0.627
Kwai Chung	Group 1 Group 2	16 20	262.1997 287.3193	53.789 90.490	13.447 20.234	-1.03	31.67	0.309
Sham Shui Po	Group 1 Group 2	20 17	241.3248 204.6705	52.343 51.840	11.704 12.573	2.13	34.15	0.040

Group 1: wind speed greater than or equal to 6 knots/hr

Group 2: wind speed less than 6 knots/hr

Table 6.10 The T-test for the effects of wind speed on build-up airborne Pb in the urban area

Site	Group	Number of Cases	Mean	Standard Deviation	Standard Error	T Value	Degree of Freedom	2-Tail Prob.
Tai Kok Tsui	Group 1 Group 2	20 18	0.7198 0.9364	0.167 0.354	0.037 0.083	-2.37	23.62	0.026
Kwai Chung	Group 1 Group 2	16 20	2.1419 3.3147	2.709 2.955	0.677 0.661	-1.24	33.32	0.224
Sham Shui Po	Group 1 Group 2	20 17	0.7207 1.4776	0.340 2.449	0.076 0.594	-1.26	16.53	0.223

Group 1: wind speed greater than or equal to 6 knots/hr

Group 2: wind speed less than 6 knots/hr

Typically speaking, in the urban areas with canyon-like streets, a strong wind may cause a downwash effect due to turbulance between the high buildings, and this may concentrate air pollutants by trapping the emission from lower floors and downwash emission from nearby elevated sources. On the other hand, if the winds are too light, the air may stagnate and the air pollutants may be accumulated. This is a complicated matter, and the exact situation in each district may obviously depend on other factors such as the areal patterns of the streets and buildings, and various characteristics of pollutant emissions or other micrometeorological conditions. It is necessary to conduct more tracements and observations.

6.5 The mixing depth

It is recognized that the lapse rate near the ground, especially on a sunny afternoon, is often superadiabatic but that at equilibrium it becomes more nearby dry adiabatic. Thus, the mixing depth is defined as the top of a surfaced-based layer in which the vertical conventional current is relatively vigorous and in which the necessary lapse is approximately dry adiabatic. It is believed that the higher the mixing depth, the greater the temperature of ground-layer air is, and this results in strong vertical turbulance and eddies near the ground.

At the campus of C.U.H.K. and in the Kowloon Tong District, the relationships between the concentration of TSP and the mixing depth is significantly positive. These reflect that the higher concentrations of TSP is implicated in the unstable atmospheric conditions, under which the stronger mixing currents and eddies near the ground may cause the resuspension of the surface dust. However, at Tai Kok Tsui, Sham Shui Po and Kwai Chung districts, the relationships are not significant. It seems that the variation of the concentration of TSP is not implicated in the stability conditions of the atmospheric at these districts (see Table 6.11)

For airborne Pb, the significantly inverse correlation between the concentration of airborne Pb and the mixing depth at Kwai Chung District is found. It reflects that the airborne Pb may be significantly dispersed by the strong conventional currents under the instable atmospheric conditions in this district. In the other districts, the correlations are not significant. The concentration of airborne Pb may not significantly vary with the variation of the stability conditions of the atmosphere.

6.6 Discussion

In the overall F-tests, the observed significance levels are greater than 0.05 level for all equations except that for C.U.H.K. (see Table 6.1). The results indicated that the goodness of fit of regression equations is very low. Rainfall, wind speed and mixing depth combined cannot be good predictors for the variability of particulate concentrations in the urban area in Hong Kong. This inference can be supported by the small values of the R square (the square of the multiple correlation), which shows the proportion of variance of Y explained by combined

Table 6.11 The relationship between mixing depth and the particulate pollution level

Site	TSP			Pb		
	B	Beta	Sign.* Level	B	Beta	Sign.* Level
C.U.H.K.	0.17	0.200	<0.1	0.00069	0.058	>0.1
Kowloon Tong	0.420	0.291	<0.1	-0.00197	-0.194	>0.1
Tai Kok Tsui	-0.196	0.193	>0.1	-0.0013	-0.165	>0.1
Sham Shui Po	-0.340	-0.170	>0.1	-0.003	-0.274	>0.1
Kwai Chung	-0.39	-0.164	>0.1	-0.05	-0.346	<0.1

TSP = mass concentration of total suspended particulates

B = partial regression coefficient

Beta = standardized partial regression coefficient

* = the significance level of the Beta is determined by the F-test (refer to Table 6.3 and 6.6)

linear influence of the independent variables, as the greatest value is 0.223, by which only 22% variability of Y can be explained by the equation. Therefore, there must be other uncertain factors which have greater influence on the particulate pollution than meteorological parameters do.

In this study, slightly or significantly inverse relationships between the concentration of TSP and the amount of daily rainfll are found at all monitoring sites. This demonstrates that the cleansing effects of the precipitation do exist. However, at the four monitoring sites in urban areas, the daily rainfall is not significant but only slightly explains the variation of the concentration of TSP. After the stepwise selection procedures, the "daily rainfall" is excluded and is a variable not included in the equation. It is believed that in the urban areas, the day-to-day fluctuations of the multitude of small, low, pollution sources and the complicated micrometeorological conditions due to the effects of densed high buildings, may reduce the cleansing effects of precipitation on the suspended particulates. However, in the open country as the campus of C.U.H.K., the amount of precipitation can significantly predict the variation of the particulate pollution in the atmosphere.

The effects of wind speed on the particulate pollution are quite complicated. In the case of Hong Kong, the effects of wind speed only have local significances, at some districts in the urban areas, the effects are even nil.

However, in the open country as campus of C.U.H.K., the effect of wind speed is significant. For the TSP, the strong wind may resuspend the surface dust and raise the concentration. For the airborne Pb, the strong wind may cause the dispersion effect and reduce the concentration of Pb.

With regard to inference or generalizations, the regression equations and their coefficients are not mentioned here, because they have only local significance. However, this is not an unusual matter because even many pollution estimating models are also based on experimental diffusion trials mainly over open country. However, it is far from complete, particularly for the densely populated cities. The process of transport and diffusion of pollutants in the metropolitan regions is very complicated and it is hard to be generalized as the effects of the following conditions are uncertain. Firstly, the conditions of pollution sources in the city are uncertain since they are complicated and multifarious. They can vary from tall-stacks to lower stacks, from isolated sources to multiple small areal sources, and from stationary sources to moving sources. Otherwise, the impacts of urban development on the dispersion parameters, i.e. the patterns of streets, the vertical development of buildings, and land use patterns are also quite uncertain. Therefore, in the metropolitan areas, source-receptor relationships, and the micrometeorological conditions are spatially and temporally varied and notwithstanding these uncertainties, it seems unreliable to estimate air concentration (ambient air quality) with the above mentioned meteorological parameters if the whole city is taken to be considered.

However, in relatively open spaces, i.e. Kowloon Tong District and campus of C.U.H.K., the effects of the meteorological parameters on the pollution level are relatively more significant than in the densely populated urban areas. In these areas, there are fewer pollution sources, and in addition to low density population and buildings, the predictions of meteorological parameters are higher as the other factors are less significant.

CHAPTER VII

CONCLUSIONS AND SUGGESTIONS

The spatial variation of particulate pollution does exist in Hong Kong. Among all monitoring sites, the highest level of pollution was detected in Kwai Chung District since numerous pollutants are emitted from the factories. It is interesting that even in the commercial-residential areas, in which fewer factories are located, the particulate pollution level is so high that the level is above the primary air quality standard, which would be harmful for the dwellers. The high level of particulate pollution in this district seems to be due to the numerous small pollution sources such as the restaurants, domestic cooking facilities and automobiles, and the congested high buildings may contribute to the poor ventilation conditions.

The vertical variation of the particulate pollution is very complicated. It depends on vertical land use patterns, ventilation conditions at the lower floors, and other uncertain factors. Therefore, the ambient air quality at the roof may not necessarily be better than that at the ground-level.

Among the airborne elements analyzed in this study, lead is cause for the most serious concern, as the airborne lead pollution levels are higher than the national maximum permitted levels in many countries. Even at the campus of The Chinese

University of Hong Kong, which lies in a nonurban area. The control programme of related emission sources must be immediately taken into action. To reduce the volume of lead in motor fuel may be the most efficient method, as the automobile is the main source of the airborne lead.

Rainfall is usually taken as the important cleansing factors for atmosphere pollution. However, in this study, the effect of this meteorological parameter is varied and seems to be of only local significance. It cannot act as a predictor for the variability of the pollution levels of the airborne particulates in the urban area.

The wind speed and the mixing depth are usually considered as the dispersion parameters in the prediction of the concentrations of the pollutants, but in this study, the effects only have local significance. In the urban area, the dispersion effect are not significance and cannot be taken as the predictors for the variation of the concentrations of the pollutants.

In the commercial-residential areas, which are congested with tall multi-storeys buildings, the dispersion effect is weak due to the poor ventilaton in the "street-canyons". Thus, the ambient air quality of airshed at such lower levels would be of considerable concern, since the pollutants may be stagnated or accumulated between the buildings, and the dwellers living at the lower floors may be directly affected.

In comparison with some big cities in the world, the present status of particulate pollution in Hong Kong is not cause for serious alarm. However, in the industrial areas and the densely populated areas, efficient control and management are urgently required as the concentrations are far above national ambient air quality standards.

Since the Clean Air Ordinance (1959) controls only the emission of smoke, other airborne pollutants, have not been adequately controlled by this regulation. This implies that under any circumstances, emitting pollutants other than smoke is not an offense against the law, no matter how extensive the degree of pollution For managing ambient air quality, an overall air quality control bill must be enacted in place of the outdated one.

Since the spatial variations in particulate pollution exist, the divisional ambient air quality standards for each land use zone ought to be set up.

For the management of atmospheric environment, the continual monitoring, evaluation and observation of the ambient air quality is necessary, but the monitoring sites must be carefully considered, as distance from the emission sources or even from the nearby high buildings, the plot of the samplers, and the ventilation conditions, can all affect the actual status of the represented regions.

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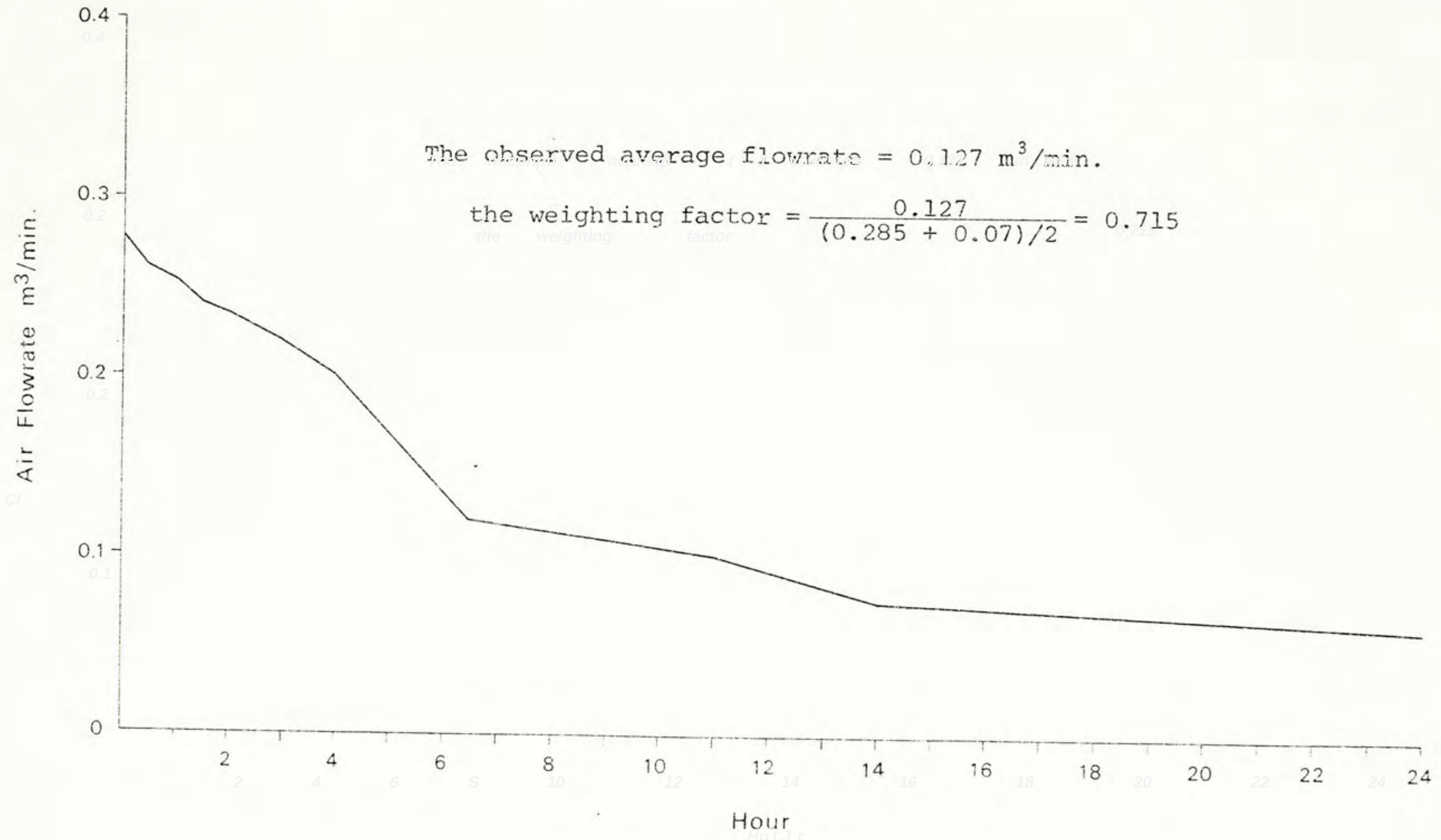
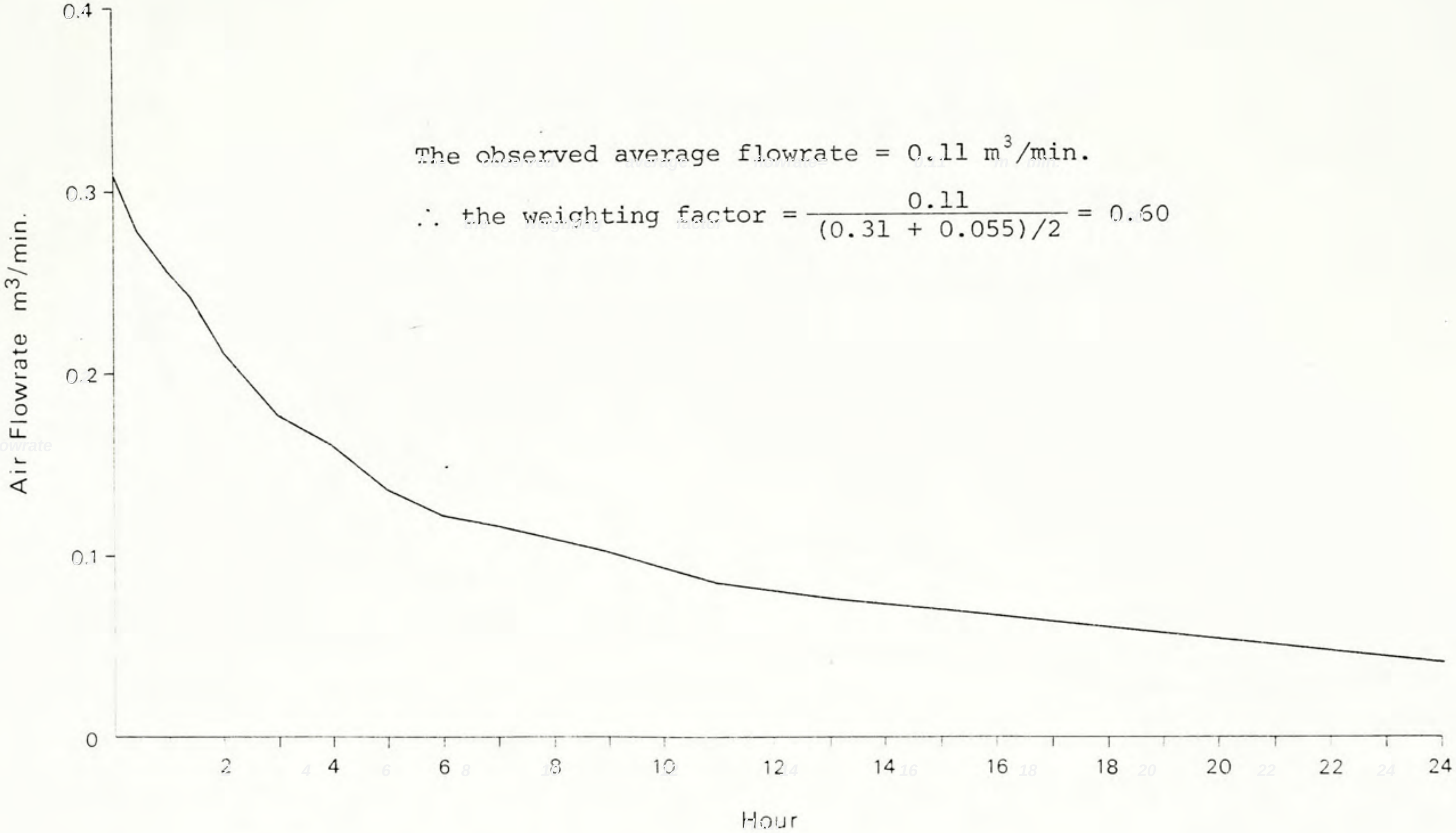
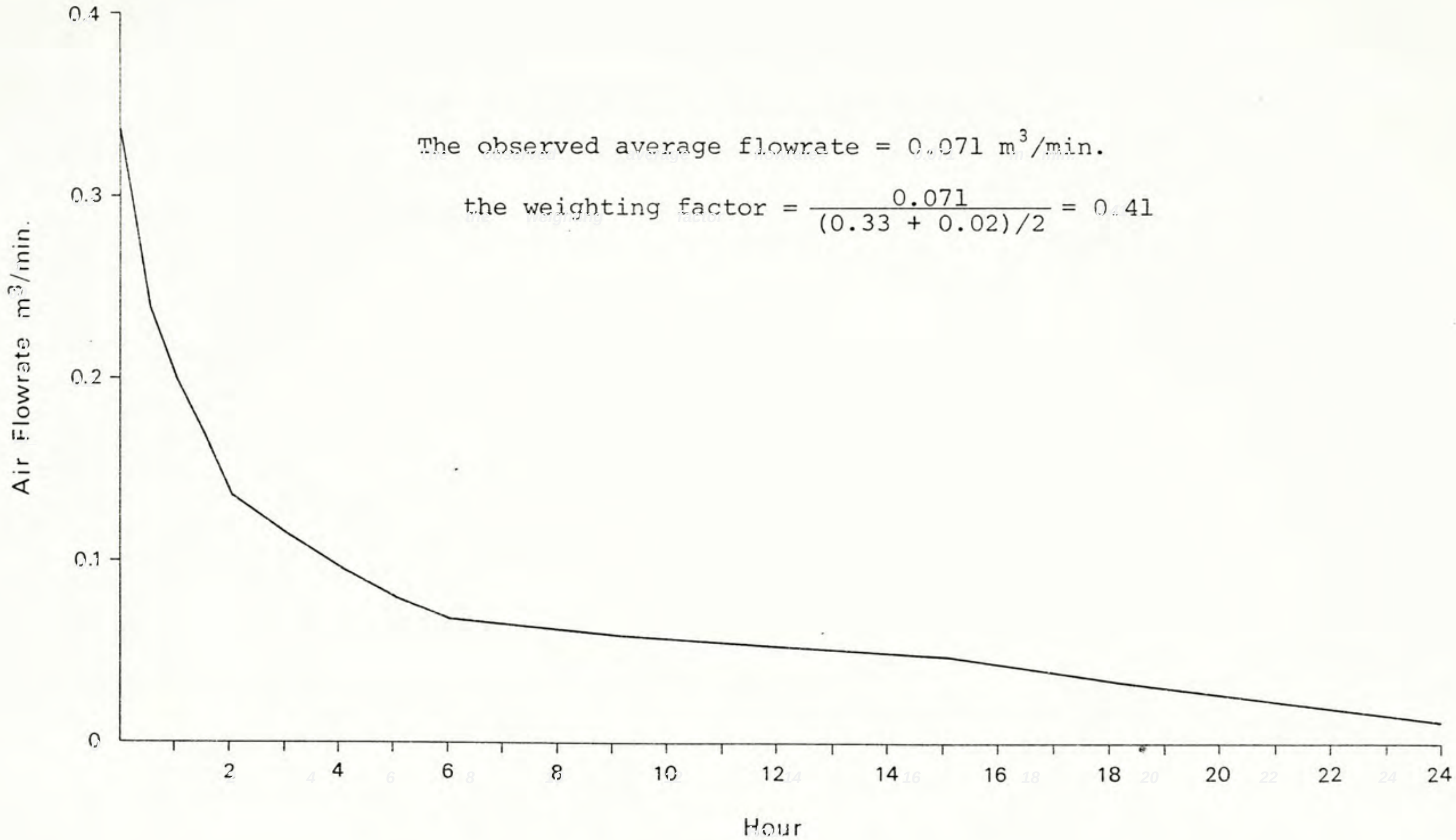
APPENDICES



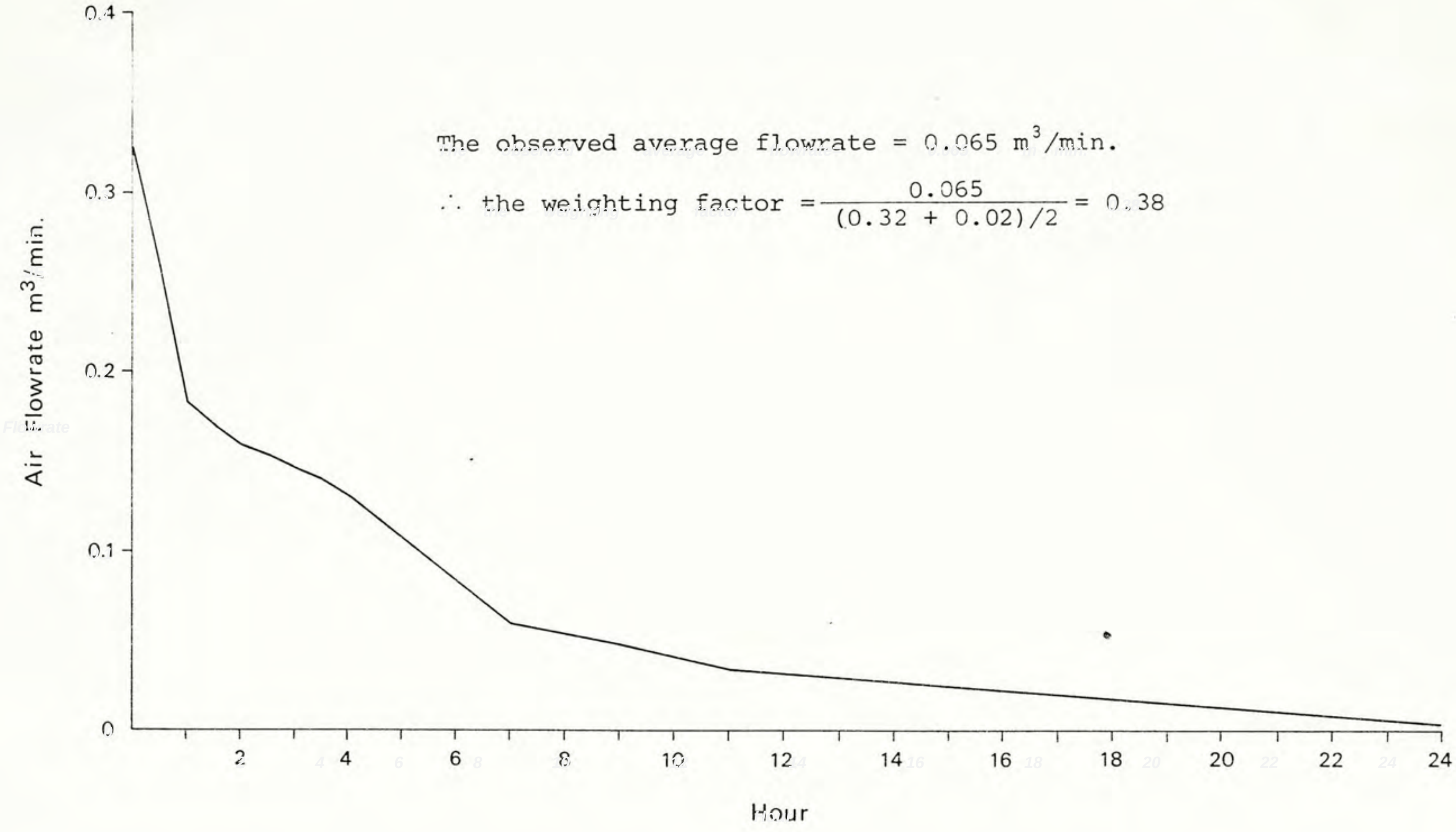
Appendix A1 The air flowrate calibration curve at Campus of Chinese University.



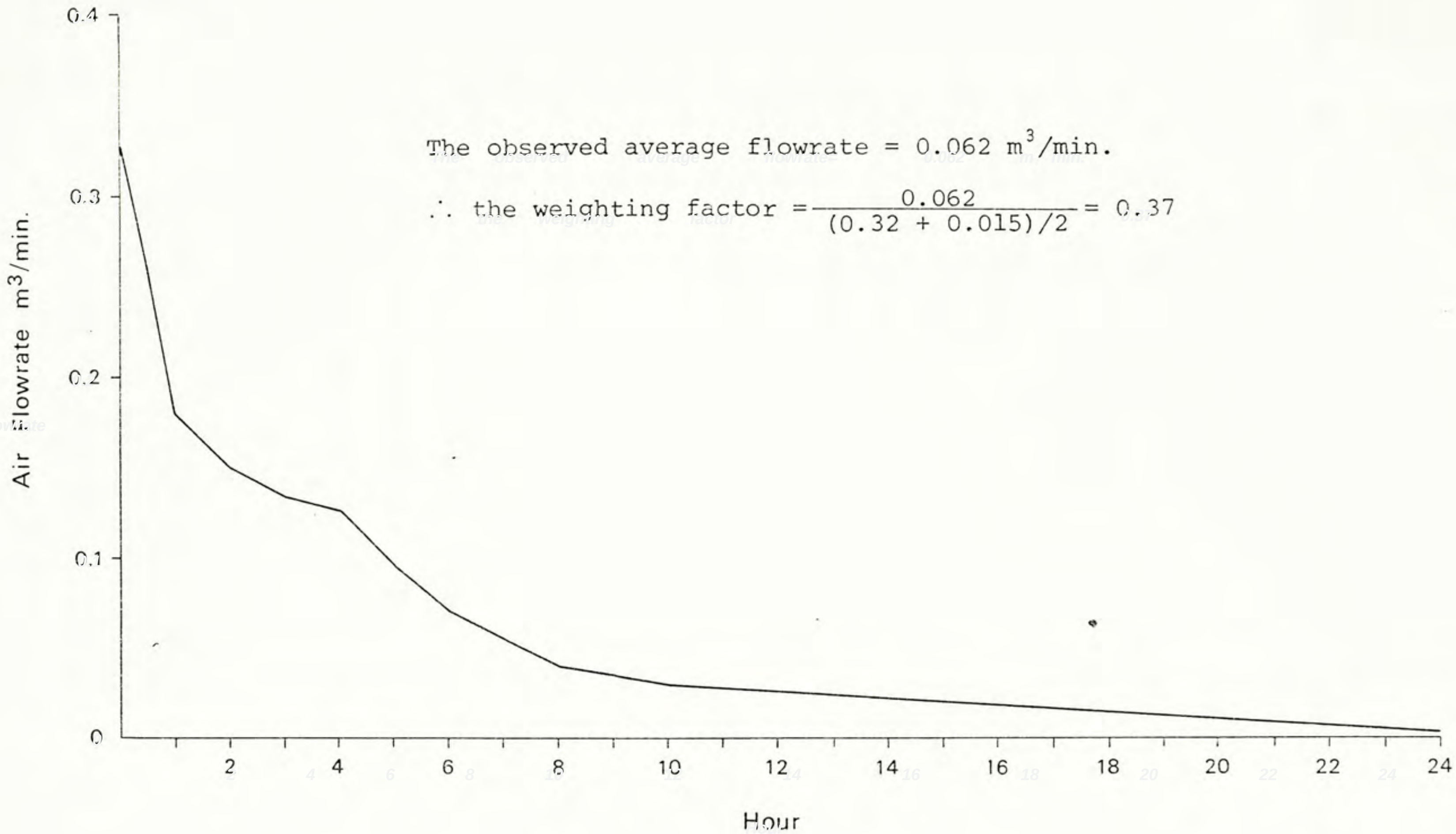
Appendix A2 The air flowrate calibration curve at Kowloon Tong.



Appendix A3 The air flowrate calibration curve at Tai Kok Tsui.



Appendix A4 The air flowrate calibration curve at Sham Shui Po.



Appendix A5 The air flowrate calibration curve at Kwai Chung.

Appendix B1 The pollution sources within 50 m distance from the monitoring site at C.U.H.K.

Source	Number	Pollutants			
		Pb	Fe	Cd	Resuspended particulate
Traff flow* volume (Tai Po Road)	27900/day	✓		✓	✓
Heavy lorries		✓		✓	✓
Meet-class† buses	144/day	✓		✓	✓
Diesel train#	56/day	✓	✓	✓	✓
Reclamation construction & electricity construction					✓

Sources: * Traffic Census (1981)

† by personal communication

by personal communication

Appendix B2 The pollution sources within 50 m distance from the monitoring site at Kowloon Tong

Source	Number	Pollutants			
		Pb	Fe	Cd	Resuspended particulate
Diesel train	56/day	√	√	√	√
Electrical train	218/day		√		√

Sources: by personal communication

Appendix B3 The pollution sources and factories within 50 m distance from the monitoring site at Tai Kok Tsui

Source	Number	Pollutants							
		Pb	Cu	Zn	Fe	Ni	Cr	Cd	Particulate
Restaurant	1	✓						✓	✓
Cooked food shop	4	✓						✓	✓
Fast food shop	2	✓						✓	✓
Cooked food stall	6	✓						✓	✓
Roasted meat shop	4	✓						✓	✓
Bakery	2	✓						✓	✓
Battery shop	1						✓		
Glass equipment	1								✓
Metal works	2	✓	✓	✓	✓	✓	✓		✓
Electrical engineering	2	✓	✓	✓	✓	✓	✓		✓
Hardware works	3	✓	✓	✓	✓	✓	✓		✓
Construction & decoration	1	✓	✓	✓	✓	✓	✓	✓	✓
Traffic flow* volume	71450/ day							✓	✓

Sources: field surveying

* Traffic Census (1981)

Appendix B4 The factories and pollution sources within 50 m distance from the monitoring site at Sham Shui Po

Source	Number	Pollutants							
		Pb	Cu	Zn	Fe	Ni	Cr	Cd	Particulate
Restaurant	4	✓						✓	✓
Cooked food shop	9	✓						✓	✓
Fast food shop	3	✓						✓	✓
Cooked food stall	18	✓						✓	✓
Roasted meat shop	1	✓						✓	✓
Bakery	2	✓						✓	✓
Metal engineering	2		✓	✓	✓	✓	✓		✓
Hardware shop	1		✓	✓	✓	✓	✓		✓
Electrical engineering	1		✓	✓	✓	✓	✓		✓
Garment factory	1								✓

Sources: field surveying

Appendix B5 The pollution sources and factories within 50 m distance from the monitoring site at Kwai Chung

Source	Number	Pollutants							
		Pb	Cu	Zn	Fe	Ni	Cr	Cd	Particulate
Textile	1								✓
Knitting	36								✓
Garment	40								✓
Thread products	2								✓
Fabric, sick, piece goods	3								✓
Dyeing	2	✓					✓	✓	✓
Printing	12	✓					✓	✓	✓
Plastic	22	✓					✓	✓	✓
Metal	19		✓	✓	✓	✓	✓		✓
Rubber products	2						✓	✓	✓
Footwear	5						✓	✓	✓
Machine works	5		✓	✓	✓	✓	✓	✓	✓
Electrical engineering	6		✓	✓	✓		✓		✓
Electroplating	4							✓	
Watch case	1				✓		✓		✓
Garage	1						✓		✓
Furniture	1	✓						✓	✓
Leather							✓		✓
Button	3	✓					✓	✓	✓
Paper products	5								✓
Food	3	✓						✓	✓
Embroidery	1								
Zip fastening	2								
Intronic	1								
Traffic flow* volume	107040/day	✓						✓	✓

Sources: field surveying * Traffic Census (1981)